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Department of Naval Architecture and Marine Engineering

STUDY OF TWIN- AND TRIPLE-SCREW SYSTEMS FOR ICEBREAKERS

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ORA Project 08121

Final Report for:

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I. Objective and Scope.

A parametric study of twin- and triple-screw propulsion systems for large icebreakers is conducted with respect to technical properties and feasibility limits. The study is devoted to the following aspects in particular:

1. Bollard thrust, ahead, conventional propeller
2. Bollard thrust, astern, conventional propeller
3. Bollard thrust, ahead and astern, special compromise propeller, designed for astern operation
4. Propulsive efficiency at advance speed of 1 knot
5. Propulsive efficiency, free running at 18 knots
6. Radial and axial clearances between propellers and hull
7. Steering and maneuverability
8. Propeller excited hull and shaft vibrations
9. Propeller strength
10. Cavitation

Further, the effect of the following parameters had to be considered:

11. Blade number, three versus four blades
12. Hub size, solid and detachable blade screws
13. Propeller diameter
14. Area and power splitting ratio, 1:1:1 versus 1:2:1
15. Powering (SHP)

The investigation is performed for three ship designs of different size:

Case I:

300' LWL, 28' Draft, 70' Beam, 8,500 Tons

15,000 to 45,000 SHP

Case II:

350' LWL, 30' Draft, 80' Beam, 12,000 Tons

30,000 to 60,000 SHP

Case III:

400' LWL, 30' Draft, 90' Beam, 15,400 Tons

30,000 to 60,000 SHP

II. The Available Disk Area.

The space which can be used for arranging propellers in the stern domain is limited by the dimensions of the ship, i.e. principally by draft and beam, and by the clearances required between hull and propeller. It is usually the aim of any design of heavily loaded propellers such as those for icebreakers to provide as much disk area as possible; the disk area is of foremost importance for the performance of such screws. It is therefore necessary to find the maximum feasible diameters and disk areas of the twin- and triple-screw systems under consideration.

A. The minimum tip submergence for the blade in its top position was specified in the contract as 8 feet minimum.

B. The maximum tip submergence is also given in the contract which states that a margin of one foot below base line must not be exceeded.

C. The lateral extension of the propulsion system is limited by the available beam in general, and in particular by the fact that the propeller shafting has to be of acceptable length and angularity. Also, engines and gears must be conveniently locatable inside the hull. These facts restrict the distance of the shaft axis from the centerplane.

The situation was studied by comparison with similar icebreaker designs. Figures* 1, 2, and 3 show existing or proposed twin-screw

*Note that all figures are given in Appendix II.

designs for which propeller arrangement plans could be found or deduced. Table I* summarizes how much space is occupied by each of the two propellers, and what percentage of the beam remains free. Less information was available for the triple-screw system. The U.S.S.R. icebreaker "Moskva", the only pertinent evidence on hand, Figure 4, could be evaluated with the help of some reconstructive assumptions.

The first part of the following evaluations was based on propeller diameter/beam ratios 0.232 for each twin propeller and 0.58 for the sum of all triple-scew diameters. The former value corresponds to about the <u>average</u> of the considered twin-screw designs, the latter was derived from the "Moskva". Both values were considered as sufficiently typical of modern design practice to result in fair comparisons. But upon Coast Guard request a second part of the analysis was then also carried through for ratios of 0.27 and 0.64 for twin- and triple-screw systems, respectively. These assumptions are close to the <u>limits</u> of the design potential, but not unrealistic.

The following maximum diameters were obtained for <u>twin-screw systems</u>:

	$D_{P_{MAX}}/B=0.232$	$D_{P_{MAX}}/B=0.27$
Case I: 300'x28'x70' ship	$D_{P_{MAX}}$ = 16.25'	$D_{P_{MAX}}$ = 19.9'
Case II: 350'x30'x80' ship	$D_{P_{MAX}}$ = 18.56'	$D_{P_{MAX}}$ = 21.6'
Case III: 400'x30'x90' ship	$D_{P_{MAX}}$ = 20.88'	$D_{P_{MAX}}$ = 23.0'

For <u>triple-screw systems</u>, the useful beam b for the sum of the triple screws is as follows:

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*Note that all tables are given in Appendix I.

		b/B = 0.58	b/B = 0.64
Case I:	300'x28'x70' ship	b = 40.5'	b = 44.8'
Case II:	350'x30'x80' ship	b = 46.4'	b = 51.2'
Case III:	400'x30'x90' ship	b = 52.2'	b = 57.6'

The propeller size limitation in the draftwise direction is 21' in Case I, and 23' in Cases II and III. So, it is less critical than the beam-wise limitation except in Case III for $D_{PMAX}/B = 0.27$, and for the center screw, when $b/B = 0.64$.

In the triple-screw case the available space b must be distributed among the three propellers. It is assumed that the sum of the propeller diameters equals b so that there is no gap between the disks as seen from behind nor any overlap. This is an acceptable arrangement aiming at the maximum possible space without unfavorable interference between propeller races*. A check showed that only small gains could be obtained by permitting some overlap so that it is hardly worthwhile risking detrimental interference effects. The maximum feasible diameters, the areas per screw, and the total disk area of the systems 1:1, 1:1:1, and 1:2:1 are shown in Table 2 for both sets of diameter limitations. Note that for the center screw, Case III, b/B = 0.64, only 23' diameter could be used because of draft restrictions.

If the beam limitations are 0.232 and 0.58, the split 1:2:1 is most advantageous for all ship sizes. The disk area gains are only small though. The split 1:1:1 results in the second highest disk areas.

*But this goal would be reached more safely by providing 1 to 2 feet clearance between the disks.

If the design is pushed to the limiting ratios of 0.27 and 0.64, the 1:1 split is best in disk area for Cases I and II, but suffers from draft limitations in Case iii. Only the split 1:1:1 is not restricted in draft so that its disk area is highest in this case while the 1:2:1 area ratio is second best in every case.

The results show that small variations in ship size and beam and draft limitations may turn one alternative from worst to best although the gains are not dramatic. For optimal solutions careful comparisons are necessary.

III. Bollard Thrust Ahead.

The thrust at zero speed of advance in the ahead direction is evaluated for 3 and 4 bladed Troost series propellers of two different blade area ratios (B3.50; B3.65; B4.55; B4.70). The thrust is found first for various diameters of individual screws as a function of power input (SHP), and later on for certain twin- and triple-screw combinations.

The calculations are limited to propellers that operate at 120 RPM in the bollard condition. For any diameter and SHP there is an RPM that will give the maximum thrust, and this RPM is in some cases larger than 120 RPM and in some cases smaller than 120 RPM. The investigation covers the commonly used pitch range of P/D = 0.5 to 1.4. The greatest thrusts are obtained at the lowest pitch ratios when SHP and RPM are kept constant. This reflects the gains due to increases in propeller diameter. Lower pitch ratios than P/D = 0.5, or still larger screws, are not recommendable, however, because of the unfavorable performance of such screws at other advance speeds.

The evaluations are based on Troost propeller charts, as published in Reference 10. The B4.70 samples are reproduced here as Figures 5 and 6. These charts have been selected because they permit convenient readings at zero advance number. The Lewis Charts, Reference 12, which are similar, were not available immediately for all parameters of interest.

A sample calculation is given in Table 3. A computer program was written for these calculations. A number of readings was taken

from the charts, and the final results were obtained by having the computer interpolate between these readings (Michigan Library Subroutine TAB). The computer output is summarized in Tables 4 through 15.

Figures 7 through 10 illustrate the results. Thrust is plotted against SHP with diameter as the parameter. The domain covers the range of common pitch ratios from P/D = 0.5 to 1.4. Boundary lines for these constant values are given to define the range of practicable propellers.

The bollard condition is normally considered as the governing design condition for icebreaker propeller systems, or else some very low advance speed (see Reference 3). In both events one would tend to select the largest screws with a reasonable pitch ratio so that the maximum possible thrust is obtained. This would lead to pitch ratios near 0.5 if compatible with other performance conditions.

IV. Cavitation.

In order to establish in which range the thrust predictions for Troost propellers can be realized in practice the occurrence of cavitation was checked early in this study.

One cavitation check was based on a curve directly applicable to Troost propellers, Figure 11 of this report, from Reference 11. On this basis, the required blade area ratio for cavitation free operation at 120 RPM and zero speed of advance was computed and plotted against thrust in Figure 12. By comparing this diagram with the curves of thrust versus SHP in Figures 7 through 10, it can be concluded that practically all propellers of types B3.50 and B4.55 are subject to cavitation. It takes about 65% to 70% blade area ratio to render, at least at lower SHP, the larger screws free of cavitation.

Since the Wageningen series propellers are not particularly suited for heavy load conditions, and have not been developed for bollard operation either, a check under the previous assumptions is conservative and does not reflect the potential improvements by special propeller designs.

To illustrate the scope of possible gains Burrill's cavitation line for heavily loaded propellers has been used for a second check, Figures 11 and 13. While the B3.50 and B4.44 propellers still appear to be insufficient the higher area ratio propellers show considerable improvement and promise satisfactory operation up to 20,000 SHP (B3.65) and 22,000 SHP (B4.70) per screw at diameters around 23' (Figures 7 through 10).

V. Comparison of Bollard Thrust Ahead for Various Arrangments.

The ahead bollard thrust is compared for three different arrangements: Twin propeller (power and area split 1:1), triple (1:1:1), and triple (1:2:1). The maximum feasible diameters for all arrangements were given in Table 2. It was attempted to make comparisons for all of the listed diameters, and also for diameters which were 15% and 30% less than maximum. But in numerous cases, mainly with smaller diameters, no acceptable pitch ratios were reached at the specified bollard RPM.

Three comparisons were made:

Comparison A:

Highest obtainable bollard thrust ahead without cavitation for each arrangement regardless of how much SHP is absorbed. The SHP will therefore differ for the design alternatives. This comparison demonstrates the bollard thrust potential. The Burrill cavitation line is used for this purpose. The evaluations are limited to B3.65 and B4.70 propellers because the lower blade area ratios are subject to cavitation. Only the largest screws in each configuration are considered since they set the limits.

Comparison B:

Bollard thrust ahead versus SHP for all arrangements regardless of cavitation. Parameters in this comparison were: Propeller type (B3.50; B3.65; B4.55; B4.70), ship size, and diameter as above. This comparison shows the thrust obtained at the expense of equal power.

Comparison C:

Highest obtainable bollard thrust ahead at the limiting SHP where the most cavitation-prone arrangements start cavitating. This comparison is limited to blade area ratios of B3.65 and B4.70. The results were obtained by means of Tables 16 and 17 fir:ing the highest SHP for which all arrangements do not calitate, using the Burrill cavitation limit.

The comparisons were performed for both levels of diameter restriction, i.e., for the sets of "average" and "limit" diameters defined in Table 2.

The results of comparison A are given in Tables 16 and 17 and Figures 14 through 17. The differences among the various arrangements are small. The trend favors higher disk areas. It is thus advantageous for "average" diameter 1:2:1 splits, while most of the twin-screw cases are best at "limit" diameters except in Case III where 1:1:1 is frequently superior.

No conclusions should be drawn from the fact that the four-bladed propeller is slightly better than the three-bladed one. This is more likely a coincidental property of the two Troost series. Similarly minor deviations in series peculiarities would also explain some seemingly unsystematic trends in the results.

For comparison B the results are presented in Tables 18 through 41, and Figures 14 through 41. The evaluation covers only those parameter variations with pitch ratios between 0.5 and 1.4.

The three systems are confirmed to be almost equivalent. At greater blade ratios, and in particular for the greatest design

area, Case III, the 1:2:1 split is only slightly superior to the 1:1:1 split.

These gains, wherever they exist, remain hardly noticable at the limit of cavitation, comparison C; this case is indicated by the arrows in Figures 19 through 41.

The cases of highest total system SHP that can be absorbed without cavitation are summarized in Table 42. It is mostly that the 1:1:1 split cavitates first.

The data of Table 42 can be used for first orientation as to the highest SHP that can be reached for each ship size. It can be expected in general, that the power of the 1:1 and 1:2:1 splitting ratio designs can be increased a few percent.

VI. The Astern Thrust of Troost Propellers at Zero Speed of Advance.

It is a well known fact that a conventional propeller is less effective in generating thrust from a given power input when rotating in the astern direction. Most normal profiles used in propeller design are asymmetrical with respect to nose and tail which results in a less favorable lift versus angle of attack characteristic when the inflow is from the tail end direction.

The magnitude of this influence can be judged by Figure 27, Reference 4, page 36, where the ratio of thrust coefficient C_T over torque coefficient C_Q is plotted against the camber ratio at 0.7 radius for ahead and astern operation. Figure 42 of this report shows an average curve derived from the above diagram and used in this work.

The camber ratio of the Troost propeller series was determined in Table 43 using data from References 6, 10 and 11.

The operating conditions are compared assuming the same power input ahead and astern. It is further assumed for simplification that the full load RPM are equal. In this case,

$$\frac{T_{ASTERN}}{T_{AHEAD}} = \frac{\dfrac{T_{ASTERN}}{p_o^2 \cdot d^2 n^2}}{\dfrac{T_{AHEAD}}{p_o^2 \cdot d^2 \cdot n^2}} = \frac{C_{TASTERN}}{C_{TAHEAD}} = \frac{(C_T/C_Q)\ ASTERN}{(C_T/C_Q)\ AHEAD}$$

Where: n = rps
p_o = nose-tail-pitch, ft.
d = propeller diameter, ft.

The quantities involved in the last expression can be read off directly from Figure 42. The results are given in Table 43. The astern bollard thrust of the Wageningen propellers under consideration can be expected to be about 80% of the ahead thrust.

The astern thrusts are plotted against SHP in Figures 43 through 46. The picture of the relative merits of the systems is of course the same as for the ahead condition, as illustrated by Tables 44 through 55, and Figures 47 through 58.

VII. The Ahead and Astern Bollard Thrust of a Compromise Screw.

In the operation of icebreakers the maneuver of backing out of and down from the ice does sometimes require more thrust than that of moving up since no accumulated momentum is there to assist.

In view of this, the Coast Guard contract calls for an evaluation of special propeller designs to operate in the astern direction.

As pointed out in previous section the inferiority of the backing performance is caused by foil asymmetry. If one wanted to carry the improvement of astern performance to the extreme it would be obviously possible to mount the screws in the opposite sense, with the foil suction sides (backs) away from the ship, and the pressure sides (faces) towards the ship. Although this procedure is not seriously suggested here, it shows to what extent the backing thrust can be improved and at what expense in forward thrust. The magnitude of the potential improvements can be estimated by reading the figures and tables previously given for ahead and astern thrust in the reverse sense.

However, the actual aim is an improvement in astern performance without overdue sacrifices in forward thrust, i.e. a compromise design.

There are mainly two possibilities of directing a design towards more balance between ahead and astern performance:

A. Reduction of profile camber throughout the blade using angle of attack for lift generation instead.

B. Selection of nearly symmetrical foils with respect to the .5 chord-length point (nose half = tail half). This implies

symmetrical thickness distributions as well as symmetrical mean lines, such as the C-series mean lines developed by DTMB.

Reducing the camber does produce a better balance of forward and astern thrust, decreasing the length of the lines in the C_T/C_Q - chart, Figure 27 of Reference 4. For a camberless screw ahead and astern thrust would be identical.

There are, however, many practical drawbacks. When the lift is produced solely by angle of attack the pressure distribution is disadvantageous with pronounced peaks at whatever the front edge is in each sense of rotation. If the pressures on the suction side have to be kept safely above the cavitation level more foil length becomes necessary than with the uniform pressure patterns of cambered foils. Besides, flow separation becomes a more serious problem. This causes inferior propeller performance at conditions not too far away from the design point.

Reduction of camber as a design measure should thus be kept within moderate limits.

If perfectly symmetrical foils would be selected the ahead and astern bollard thrust would become equal. This measure would turn the characteristic curves in Figure 27, Reference 4 into a horizontal position. It may also cause a decline of thrust per SHP for the following reason. In order to avoid excessive pressure loading of the foils at both ends instead of just at the trailing edge, longer foils must be used if the peak pressures are limited by cavitation. This means greater frictional losses and lower thrust.

This disadvantage can usually be kept well within acceptable limits. The symmetrical foil or nearly symmetrical foil can therefore

be recommended if improved backing thrust per SHP is desired. The consequence of at least some deterioration of forward thrust is in common to all methods of improving astern operation.

In order to estimate how much thrust can be expected from a compromise propeller, for which $T_{ASTERN} = T_{AHEAD}$, one can read the mean value between ahead and astern operation from Figure 42:

$$C_T/C_Q = 6.19,$$

so that the following ratio is found:

$$\frac{T_{COMPROMISE}}{T_{AHEAD}} = \frac{(C_T/C_Q)\ CPMPR.}{(C_T/C_Q)\ AHEAD} = \frac{6.19}{(C_T/C_Q)\ AHEAD}$$

Propeller	B3.50	B3.65	B4.55	B4.70
(C_T/C_Q)AHEAD	6.95	6.78	6.87	6.71
T_{COMPR}/T_{AHEAD}	.891	.913	.901	.923

The table shows that in the average one would obtain about 90% of the thrust otherwise reached in the ahead condition.

With the above ratios, compromise propeller thrusts of individual screws, Figures 59 through 62, and systems, Tables 56 through 67 and Figures 63 through 74, are given in the appendices. The system trends are the same as in earlier cases.

It is not implied by the selection of the example that a fully balanced ahead-astern behavior has to be the aim. Since forward motion is the predominant mode of operation of the ship it seems one should rather not go too far in sacrificing ahead performance.

The backing ability is also dependent on the propeller arrangement because of the resistance due to the propeller race. This

suggests gentle lines in front of the propellers and a sufficient axial clearance. The race should not hit the hull too frontally when backing. Similarly, the appendages should be designed for low resistance in the reversed flow direction.

VIII. Hub Size Influence.

The hub diameter ratios of Troost propellers are 0.18 for the B3 series and 0.167 for the B4 series. Icebreaker hubs are larger for strength reasons and in particular when detachable blades are used. The influence of hub size shall be investigated comparatively for solid propellers of 0.21, and detachable blade screws of 0.32 hub-diameter ratio.

It should be mentioned that an equation to account for large hubs was given by Milano, Reference 3:

$$T_{\text{Large hub}} = K_1 \cdot T_{\text{Troost}},$$

where $K_1 = 0.97$ for solid screws ($x_h = 0.21 \ldots 0.22$),

$K_1 = 0.86$ for detachable blades ($x_h = 0.32 \ldots 0.35$).

It is felt that these corrections are excessive. The factors K_1 are derived from a DTMB report by Shultz, Reference 5, in which the decrease of the ideal thrust loading coefficient C_{T_i} with increasing hub diameter ratio x_h was discussed. Milano adopted these reductions directly and seems to have overlooked that the absorption of input power (C_{P_i}) decreases, too. If the power input is raised to the previous level (by increasing the pitch or the RPM) a substantial part of the thrust loss is recovered. It should be kept in mind, though, that the large hub propeller needs longer, less efficient profiles to avert cavitation.

A different approach was used in an attempt to estimate the inevitable thrust losses for large hubs. The propeller efficiency is determined at a small advance number $J \ll 1$, $\lambda_i \approx 0$, and it is assumed that the efficiency loss percentage caused by the difference

in hub size equals the thrust loss percentage at zero advance speed, the power input (SHP) being the same. The propeller efficiency can be represented as product of ideal efficiency η_i (ideal fluid, momentum theory) and blade efficiency ξ (losses in real fluid).

$$\eta_o = \eta_i \cdot \xi$$

The change in expanded blade area ratio, i.e. in thrust generating area, is for large hubs according to Reference 6, page 125:

$$\frac{\Delta a_E}{a_E} = 1.1 \cdot (x_h - 0.18) \text{ for Troost B3 series,}$$

$$\frac{\Delta a_E}{a_E} = 1.1 \; (x \; - 0.167) \text{ for Troost B4 series.}$$

In our analysis,

x_h = 0.21 for solid propeller

x_h = 0.32 for detachable blade propeller

The area losses $\Delta a_E/a_E$ are thus:

	Solid	Detachable
B3	0.033	0.154
B4	0.047	0.167

It must be supposed that about the same blade area ratio is required to keep the large hub propeller free of cavitation. The area lost at the hub must be replaced at other radii. The foils must be lengthened by about the same percentage. The ideal thrust loading coefficient is defined as below and increases with hub size:

$$C_{Ti} = \frac{8\,\Gamma}{\pi \rho (D^2 - d_h^2) V_A^2} \cdot \frac{1}{1 - 2\varepsilon\lambda_i}$$

where ε = mean drag-lift ratio

V_A = advance speed, $V_A \ll 1$.

λ_i = hydrodynamic advance number,

$$\lambda_i = \frac{V_A}{\pi n D} \cdot \frac{1}{\eta_i} \ll 1,$$

hence: $\frac{1}{1-2\varepsilon\lambda_i} \approx 1$

It follows that C_{T_i} is proportional to the factor:

$$\left(1 - x^2_{h\ \mathrm{TROOST}}\right) \Big/ \left(1 - x^2_{h\ \mathrm{LARGE\ HUB}}\right)$$

Incidentally, the same correction would hold with close approximation for the power loading coefficient C_{P_i} which is also proportional to $(D^2-d_h^2)$. Both are thus raised by the factor:

	Solid	Detachable
B3	1.02	1.17
B4	1.05	1.20

From this the following changes in η_i can be estimated from the Kramer chart at $\lambda_i \approx 0$.

	Solid	Detachable
B3	0.998	0.98
B4	0.995	0.98

This demonstrates that under the assumption of equal power input the ideal efficiency of large hub propellers is only little smaller than that of regular hub size screws.

There is however a secondary effect upon blade efficiency caused by lengthening the foils. For the increase in mean lift-drag ratio ε

corresponding to this influence it can be estimated from foil data that ϵ must be multiplied by:

	Solid	Detachable
B3	1	1.1
B4	1	1.1

The blade efficiency ξ would be reduced according to Figure 75 by the factor:

	Solid	Detachable
B3	1	0.98
B4	1	0.98

The rounded total reduction in propeller efficiency is given by the following factors:

	Solid	Detachable
B3	0.995	0.96
B4	0.995	0.96

The thrust losses of a redesigned large hub screw at zero advance speed are of the same order. Milano's thrust loss percentages are much higher because they were based on overestimated η_i losses while the change of blade efficiency was ignored.

IX. Propulsive Efficiency at Speed of Advance of One Knot.

The propulsive efficiency is defined as: $\eta_P = \eta_o \cdot \eta_H \cdot \eta_r$

η_o = open water efficiency

η_H = hull efficiency

η_r = relative rotative efficiency

The open water efficiency was read from the charts, Tables 5 and 6, and similar ones for other propellers. The readings were taken for $J = V_A/n \cdot D$ with V_A = 1 knot and n = 120 RPM = bollard RPM. The change of n when V_A is increased to 1 knot is negligible as shown in the sample calculation, Tables 68 through 70. The sample illustrates further details of the procedure, too. The relative rotative efficiency is set to unity throughout.

For the hull efficiency of a multiple screw system the following expression is derived:

$$\eta_H = \frac{R \cdot V_S}{(TV_A)_{TOTAL}} = \frac{R \cdot V_S}{\sum_i (T_i \cdot V_{A_i})} = \frac{1}{\sum_i \frac{T_i}{R}(1-w_i)} = \frac{1}{\sum_i \frac{T_i}{T}\frac{(1-w_i)}{(1-t_i)}} \approx \frac{1}{\sum_i \frac{SHP_i}{SHP}\frac{(1-w_i)}{(1-t_i)}}$$

where: R = resistance

V_S = ship speed

V_A = propeller advance speed

w = wake fraction

t = thrust deduction fraction

The last step assumes that power split and thrust split are about equal. In the actual calculations the area splitting ratio has been substituted here.

At an advance speed of 1 knot the following data were estimated from similar cases, Reference 7:

Twin Screw:

$w = t, \eta_H = 1$

Triple Screw:

Center screw: $w = 0.04$, $t = 0.03$

Outer screws: $w = t$

The sample, Table 70, shows that the hull efficiency is unity for all practical purposes.

The propulsive efficiency equals the open water efficiency at this low speed therefore.

The results are shown in Tables 71 and 72 and Figures 76 through 87. It comes as no surprise that the differences between the systems are small. They conform with the bollard thrust trends as could be expected with that little speed difference.

X. Propulsive Efficiency at Speed of Advance of 18 Knots.

The icebreaker designs are assumed to operate at 18 knots free running speed. The evaluation of their propulsive efficiency is similar to the procedures of the previous section with one main exception; in the low speed case the circumstances of ice operation determine the SHP which could vary in wide limits, whereas the SHP, free running, is a single value depending on the resistance of the design, i.e. its EHP, and its propulsive efficiency, both unknown.

The EHP can only be estimated from series data at this stage. Series 60 (C method), and Taylor's standard series both fail to give acceptable results because the icebreakers differ strongly from the series hull shapes, and their form parameters are not covered satisfactorily by the series.

An attempt to use Ayre's method of EHP estimation, sample presented in Table 73 based on Reference 10, yields results which are also not consistent in themselves with respect to ship size, but are at least in the right range in comparison with similar ships. About 10,000 EHP seem to be needed to go 18 knots. Since all obtainable estimates were not fully satisfactory it was decided to cover a range of SHP so that the curves can be used more specifically as soon as more reliable EHP data are available.

The SHP range was chosen wide enough to include powers higher than those expected as necessary for 18 knots in order to keep the data applicable for higher service speeds if such should be selected later. The following power range was covered:

Ship size Case I: 6,000 to 30,000 SHP

Ship size Case II: 9,000 to 39,000 SHP

Ship size Case III: 6,000 to 36,000 SHP

The comparisons were conducted for the systems pitched for the best bollard thrust because it is common and recommendable practice to design icebreaker propulsion systems for very low or zero design speed. The pitch ratios and propeller diameters chosen for bollard operation and used in the following are summarized in Tables 74 and 75.

The possibility of cavitation was ignored in selecting the best bollard thrust systems as well as in finding the propulsive efficiencies. This was done on the assumption that while the Wageningen series propellers might cavitate in some states the redesigned special icebreaker screws could be kept free of cavitation through most of the investigated SHP range. However, the findings for SHP in the upper domain should be interpreted cautiously.

The relative rotative rotative efficiency was again assumed to be unity although this neglects the slight advantages that triple screw systems should have over twin systems at this speed.

The hull efficiency of the center screw is expected to be more favorable than that of the outer screws of triple or twin systems because of the beneficial influence of the boundary layer energy recovered from the wake by the center screw. This results in a wake fraction exceeding the thrust deduction fraction, thus $\eta_H > 1$. The following data, Table 74, were adopted as estimates for w and t after analyzing some similar designs and available equations. It was felt that these data were typical enough for the purpose of preliminary design comparisons. A thrust deduction fraction of only 0.15

may sound optimistic even though w is estimated relatively low, too, but in our opinion this low level of t, which results in $\eta_H \approx 1.13$, can be reached by successful stern designs.

Although the center screw alone reaches substantial gains in η_H a lot of this is averaged out in triple-screw systems. The results are $\eta_H = 1.03$ for the 1:1:1 power split, and $\eta_H = 1.046$ for the 1:2:1 split. For derivation see Tables 78 and 79.

The number of revolutions at which the propellers absorb the SHP must be determined by a trial and error procedure outlined in the sample in Tables 76 through 79.

The evaluations were performed for Troost B3.65 and B4.70 propellers; it could be shown by a few checks that the conclusions would be the same for the lower aspect ratios.

The results are presented in Tables 80 through 82, and Figures 88 through 92. The tendencies differ appreciably in comparison with the bollard condition. In all investigated cases, predominantly so in the lower SHP range of each ship size, the power split 1:1:1 is best, 1:2:1 second best and 1:1 weakest.

The differences in propulsive performance at 18 knots stem from the fact that the pitch ratios were selected for the bollard condition and are not optimal when free running. The twin system and the 1:2:1 split are associated with lower pitch ratios than the 1:1:1 system, and their pitch is less than optimal at 18 knots. The losses in this free running condition under partial load greatly exceed the gains in hull efficiency experienced by the triple systems.

These losses can be reduced somewhat by proper designing:

A. One can try to work with profiles that perform better at negative angles of incidence as associated with the "underpitch" at 18 knots.

B. If a little bollard thrust is sacrificed more pitch can be permitted. This measure can also be termed: Designing for higher speeds somewhere between bollard and free running condition.

It should be noted that the desired free running number of revolutions N= 150 RPM could not be maintained exactly since the design parameters were fixed by other assumptions, but it is well within the range of variation covered here.

XI. <u>Steering and Maneuvering</u>.

Twin-screw icebreaker designs generally have some difficulties to provide sufficient maneuverability, in particular at lower speeds, because the centerplane rudder, usually installed, is operating outside of the propeller races except perhaps for the greatest rudder angles.

In a triple-screw design with the rudder arranged behind the center-screw the propeller-induced inflow into the rudder supports the rudder action beneficially.

The magnitude of this effect was studied by comparing the rudder normal forces per unit area for a twin-screw design to those for the triple-screw version. It was assumed in this context that the twin propeller races do not hit the rudder whereas in the triple-screw design the rudder is fully immersed in the center-screw race. In most practical cases the situation is a little less extreme so that the twin system would look somewhat more favorable than in this investigation.

The ratio of the rudder forces as defined above is derived in tables 83 through 85. As a result the triple-screw rudder force per unit area exceeds that of the twin-screw case by a factor of $1 + C_T$, where C_T = thrust loading coefficient. This answer is independent of the rudder angle while the advance speed is of influence as it is contained in C_T.

The procedure of determining the function $(1 + C_T)$ when SHP, diameter, and propeller advance speed are given is also outlined in tables 83 through 85. For an analogous sample see also table 76.

The rudder force comparison was carried out for the three ship size cases, propellers of type B3.65 and B4.70, and for both triple-screw versions (1:1:1 and 1:2:1) relative to the twin-screw case. Only two ship speeds, 1 knot and 18 knots, could be considered, rather than the speeds of 2, 10, and 18 knots called for in the contract, because of time and budget limitations. The speed of ten knots can, however, be judged by comparison with the two extremes.

The equilibrium RPM at 1 and 18 knots were already at hand from previous calculations in sections IX. and X. so that it became preferable to disregard the low speed of 2 knots.

Diameter and pitch of each version were again selected as optimal with respect to bollard thrust, "limit" diameter condition. They are summarized in table 75.

The results are displayed in tables 86 through 97 and figures 93 through 101. It is obvious that major gains are obtained: About 50 to 100% more normal force at the free running condition, the more the higher the abscissa value of "free-running SHP", and up to a factor of 750 in the "full power"-"low speed" operation at 1 knot. At this speed, however, the twin-screw rudder normal force is only small so that the absolute value of the triple-screw rudder forces might still be unsatisfactory.

If absolute rudder normal forces would have to be estimated one would first find the twin-screw force: $N = c_N \cdot \frac{\rho}{2} V^2 A$

and multiply by $(1 + C_T)$ from the graphs for the triple-screw answer. For notation see table 83.

XII. Strength.

The subject of propeller strength is an essential one in icebreaker design; the operational reliability of the ship depends on the ability of the blades to withstand not only the loads due to the propulsion forces, but also those caused by ice impact which may be a multiple of the former.

In order to evaluate the strength characteristics of the design alternatives a comparison between triple-screw systems (1:1:1, and 1:2:1) and twin-screw systems (1:1) was performed. The propulsive stresses were determined for the bollard condition, n = 120 RPM, as a function of SHP. The maximum feasible diameters were chosen in accordance with table 2, "limit" conditions. The bollard thrust of each screw could be obtained from ealier results, tables 5 through 15, or figures 7 through 10, ignoring cavitation. Actually, in evaluating the stresses by computer the bollard thrust was recomputed by an equivalent subroutine. The computations are limited to the Troost series B3.65, and B4.70 propellers; the smaller blade area ratios are more subject to cavitation so that the comparison would be less reliable.

The propulsive stress equations for Troost propellers are derived in tables 98 through 100. The critical stress occurs usually at the trailing edge so that the comparisons are made for this point.

The results for thrust, torque, and stress are summarized in tables 101 through 103 for the three ship sizes. Figures 102 through 104 also show the stress ratios, triple-screw to twin-screw arrangements, plotted versus SHP.

For the design alternatives under comparison there are generally some disadvantages of the triple-screw systems although they are small and of no practical significance.

The reason for the equivalence in stresses appears to be that the total disk areas of the systems are nearly the same so that the loads per blade are smaller with the triple-screw systems, but the blade dimensions are also smaller.

It was stated in the proposal that the triple-screw systems would have the lower propulsive stresses if the dimensions of each screw were the same as in the twin-screw case. This conclusion seems to be confirmed indirectly by the results, but it must be added: Stress reductions with greater number of propellers should only be expected if the total disk area with 3 screws somewhat exceeds that of the twin-screw version.

It should be noted at last that the absolute stress level is extremely low in all cases. The great blade area ratios necessitated by cavitation requirements, when using Troost propellers, results in root profiles that are overdimensioned from the strength viewpoint. It is believed, however, that the changes in propeller shape when designing for a higher admissable propulsive stress would affect twin- and triple-screw systems in about the same manner so that the overall conclusions would remain the same.

XIII. Vibrations.

It is always an important design goal to keep hull and shaft vibrations within acceptable limits. This can be accomplished by avoiding resonant conditions, and besides by minimizing the periodic excitation forces acting upon propeller and hull.

The elastic properties and natural frequencies of hull and shafting are not yet known in the early stages of a design so that the determination of resonances and critical propeller speeds must be postponed until the design has been worked out in sufficient detail.

But it is possible to direct the preliminary design work towards a low level of excitation forces by seeking favorable propeller arrangements.

Although direct measurements in model tests would certainly give the most reliable predictions the attempt can be made to judge different configurations on a theoretical basis. The theory, in its range of validity, has the advantage of showing more clearly the influence of the important parameters.

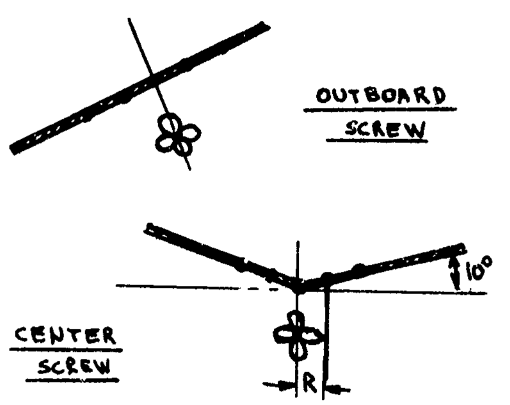
In the context of propeller-excited hull and shaft vibrations the clearances between propeller and hull, axially and radially, are known to be the most significant factors among those that the designer can control.

It was therefore undertaken to compare the various icebreaker propeller arrangements from the viewpoint of the propeller-induced vibratory excitation forces acting on the hull. These were determined using a theory and results by Breslin as outlined in references 14 and 15. The theory assumes uniform inflow into the propeller

disk and finds the pressure fluctuations at given distances from the propeller caused by the rotation of the blades. The pressure is split up into components due to thrust loading (thin foil) and to finite foil thickness effects.

The influence of the presence of the hull plates upon the pressure field are neglected, and must be corrected for later by a so-called intensification factor. This factor, a "wall effect" correction, is not well known; it should depend on the clearance because the flow pattern should be changed more drastically by the wall when the gap is small. Reference 14 recommends a factor of 2, but this can only hold for some average clearances.

With these and all other limitations of the theory in mind, what is the use of its results? It can be assumed that the results can serve for orientation as to the relative merits of different arrangements although the absolute force predictions are not correct. The results should also be indicative of what gains may be expected when varying the clearance. The study was conducted with respect to the forces exerted by the propeller flow upon a flat plate abreast the screw (see sketch) which simulates the outer screw situation, and also for a propeller operating under two intersecting flat plates of 10° rise angle each, which is similar to the center screw situation (see sketch).



Parameters in this study were:

Ship speed:	0, and 18 knots (Bollard, and free running condition).
Propeller type:	B3.65, B4.70.
SHP, thrust:	Variation as for earlier evaluations, ignoring cavitation.
Clearance:	Between 0.1 D and 0.6 D.
Diameter:	The "limit" diameters for each ship size.

The procedure in obtaining the pressures on the hull and subsequently the forces by integration is described in Tables 104 through 106. The results are given in Tables 107 through 118, and figures 105 through 111.

Tables 107 through 112 and figures 105 through 110 relate to the free-running condition. The alternatives that are compared here are the same that were selected in an earlier paragraph (X) for optimal bollard performance. The tables give the absolute vibratory forces, and the ratios force/thrust for various clearances. The figures only show the force/thrust ratio as function of thrust.

This ratio reaches values of up to 20% in some cases of small clearance. It is decreasing rapidly when the clearance is increased. When the clearance is 0.3 D or more the ratio does not vary much with the thrust any longer.

The four-bladed propellers produce noticeably lower levels of excitation.

For a given number of blades, when the clearance is low, the 1:2:1 center screw causes the greatest vibratory forces, followed by the 1:1:1 center screw. The twin propellers are a little lower than this, but higher than the outer screws of the other alternatives.

At higher clearances the tendencies are partly reversed, and the twin screw alternative becomes least favorable.

In the bollard condition, figure 111, and Tables 113 through 118 the force ratio is practically independent of the thrust, and of the propeller arrangement and ship size, so that the results can be plotted against clearance in a single diagram conveniently. The force ratio is smaller than in the free-running condition, i.e., less than 4 percent in all cases. The bollard thrust is much greater, however, so that the absolute excitation forces are about of the same magnitude in both cases.

The tendencies with respect to clearance, and number of blades are also in close agreement in the two conditions. It should be noted that the low force ratios of less than one percent which are obtained in some cases are less trustworthy than the others because the integration scheme has only poor resolution when dealing with small pressures.

Despite the limitations in the theory applied here and some shortcomings in the evaluation procedure it is believed that valid recommendations can be given to the designer in the following respects:

a) The four-bladed propeller is superior to the three-bladed screw in view of its lower hull vibration excitation.

b) Great returns for an increase in clearance are obtained up to 0.2 D. From there on, every clearance increase of 0.1 D reduces the force amplitudes by only about 25 percent or less.

It is therefore recommended to limit the clearance to about 0.2 D because otherwise the sacrifices of propulsive performance and bollard thrust are becoming unduly great. If with these

clearances vibration problems should still be of any concern the cure should be sought in properly avoiding resonant conditions rather than further reducing excitation.

A last comment as to shafting vibrations which have not been considered in the foregoing. These vibrations which are caused by non-uniform inflow into the propeller cannot be analyzed without some experimental data about the flow. It can be inferred, however, that the recommended radial clearance of 0.2 D is sufficient from this point of view, too. This statement is based on the systematic comparisons of wake harmonics for various stern configurations in reference 7, which show only little effect on the velocity amplitudes of each harmonic by variation of the radial coordinate. This makes it unlikely that in the case of shaft vibrations any major gains can be obtained by clearance variations if the clearance is of the order of 0.2 D or greater.

XIV. Propeller Arrangement and Stern Shape.

The most favorable propeller arrangement from the viewpoints of hydrodynamic performance, cavitation and vibrations is one where the inflow into the propeller disk is uniform except that in the same time one wants to recapture as much of the energy concentrated in the viscous wake as possible. These considerations would call for ample axial propeller clearances, in particular for the outer screws which cannot serve for wake energy recovery anyhow.

It must be realized on the other hand that whatever improves the uniformity of inflow into the propeller is in the same time instrumental in making the propeller more accessible to ice inflow. Conversely, any protective shape that keeps the ice away from the screw would also tend to deteriorate the hydrodynamic and vibratory performance.

Specifically, in comparing the present U.S. Coast Guard line designs M4 and M5, the conclusion would be that the former gives the outer propellers better inflow, but less ice protection. The M5 design has the outer screws operating closely behind a flat shoulder in the stern waterlines. This will probably result in separation and high EHP in the free-running condition. The performance loss in the bollard condition may be even more severe since the propeller suction field in the ahead operation finds a great area of attack so that the useful thrust is reduced. Similarly, in backing at low speed the thrust deduction force caused by the shipstream pressures upon the hull should be noticeable.

The advantages of the M5 lines must be sought in the reduced vulnerability of the outer screws in ice; this is an essential feature, and it appears justified therefore to examine the properties of this design more closely in model tests.

The authors would recommend a compromise form with more moderate shoulders and a slightly greater axial propeller clearance for the outer screws. The radial clearances should be selected as small as compatible with vibrational standards. The study in section XIII seems to indicate that nothing substantial can be gained by increasing the radial clearance above 0.2 D. This is in agreement with common design practice.

The propeller tip submergence is generally selected so as to avoid air suction and/or excessive propeller-induced vibratory forces on the stern. For an icebreaker it is the more stringent design aim usually to assure that the average size ice block when floating on the water surface be not sucked into the disk. The actual submergence should therefore be related to the thickness of the ice to be broken.

XV. General Conclusions.

None of the systems show major advantages in the bollard condition. The tendencies go with the available disk area. This makes the 1:2:1 system slightly superior at "average" diameters whereas the twin system is best when "limit" diameters are assumed. The 1:1:1 system follows up closely on second place in almost every case.

The astern and compromise design performance at zero advance speed, and the efficiency at one knot are in line with the above tendencies.

The 1:1:1 split performs best in the free-running condition while the other two are underpitched for free running under partial load.

Both triple-screw systems show great gains in maneuverability relative to the twin system.

All versions are practically equivalent from the strength aspect.

The vibratory forces acting on the hull are markedly smaller for four-bladed propellers than for three-bladed ones. Otherwise, in particular if the recommended radial clearance of 0.2 D is selected, the differences among all systems under comparison are insignificant.

The performance gains by triple-screw systems are thus only marginal; but these systems have important secondary advantages with respect to steering, and reliability. Since the availability of the ship and therefore the effectiveness of the whole investment depend on the reliability of the propulsion system the triple-screw systems deserve preference.

The question which splitting ratio to chose is less significant. We believe that the 1:1:1 split is more recommendable because it promises a good balance between bollard and free-running performance.

XVI. Acknowledgement.

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APPENDIX I: TABLES

TABLE 1 DIAMETERS FOR TWIN SCREW SYSTEMS

a. AVERAGE VALUES FROM EXISTING DESIGNS

(BASED ON FIGURES 1-3, APP. II)

Fig. No	Propeller dia. / Beam	Space between prop's / Beam	Side Spacing / Beam
1	0.210	0.111	0.234
2	0.241	0.138	0.190
3	0.244	0.082	0.214
Average	0.232	0.110	0.213

b. DIAMETERS (AVERAGE AND LIMIT*)

CASE NO., LENGTH, BEAM, DRAFT. [FT]	AVERAGE DIAMETER [FT]	LIMIT DIAMETER [FT.]
I 300 × 70 × 28	16.25	18.90
II 350 × 80 × 30	18.56	21.60
III 400 × 90 × 30	20.88	23.00**

* LIMIT DIAMETER FROM COAST GUARD SUGGESTION OF (PROP. DIA. / BEAM) = 0.27

** LIMITED BY DRAFT RESTRICTION.

TABLE 2 MAX FEASIBLE DIAMETERS AND AREAS

ARRANGEMENT		CASE	AVERAGE VALUES (*)			LIMIT VALUES (**)		
			DIAMETER FT	AREA/SCREW [FT²]	TOTAL AREA [FT²]	DIAMETER [FT]	AREA/SCREW [FT²]	TOTAL AREA FT²
TWIN SCREW		I	16.25	207.5	415.0	18.90	280.6	561.2
TWIN SCREW		II	18.56	270.6	541.2	21.60	366.4	732.8
TWIN SCREW		III	20.88	342.5	685.0	23.00	415.5	831.0
TRIPLE SCREW 1:1:1		I	13.50	143.1	429.3	14.93	175.1	525.3
TRIPLE SCREW 1:1:1		II	15.46	187.7	563.1	17.07	228.9	686.7
TRIPLE SCREW 1:1:1		III	17.40	237.8	713.4	19.20	289.5	868.5
TRIPLE SCREW 1:2:1	C.S	I	16.88	223.9	443.1	18.56	270.4	540.8
TRIPLE SCREW 1:2:1	O.S	I	11.81	109.6		13.12	135.2	
TRIPLE SCREW 1:2:1	C.S	II	19.20	289.5	580.1	21.21	353.4	706.8
TRIPLE SCREW 1:2:1	O.S	II	13.60	145.3		15.00	176.7	
TRIPLE SCREW 1:2:1	C.S	III	21.62	367.0	734.0	23.00	415.5	831.0
TRIPLE SCREW 1:2:1	O.S	III	15.29	183.5		16.27	207.8	

* Found from existing designs

$D_{MAX}/B = 0.232$; $b/B = 0.58$

** Set by Coast Guard :

$D_{MAX}/B = 0.270$; $b/B = 0.64$.

TABLE 3. SAMPLE CALCULATION

BOLLARD CONDITION THRUST

Let's take $D = 16.0$ ft, SHP $= 10{,}000$,

$n = 120$ RPM $= 2$ RPS ; $\rho(59°F) = 1.9905 \dfrac{lb\ sec^2}{ft^4}$.

$$K_Q = \frac{Q}{\rho n^2 D^5} \text{ . where } Q = \frac{550 \cdot SHP}{2\pi \cdot n\ [RPS]},$$

So $K_Q = \dfrac{550\ SHP}{2\pi \rho n^3 D^5} = \underline{43.97 \dfrac{SHP}{n^3 D^5}}$

$$K_Q = 43.97 \frac{10000}{2^3 \cdot 16^5} = 0.0524$$

Entering the Henschke diagram for the above K_Q and $J = 0$ we find:

$\underline{P/D = 0.891}$

For this P/D and $J = 0$ we find

$\underline{K_T = 0.395}$

The thrust can be found now by:

$$T = \rho n^2 D^4 K_T = 1.9905 \cdot 2^2 \cdot 16^4 \cdot 0.395 = 20.62 \cdot 10^4$$

$\underline{T = 20.62 \cdot 10^4 \text{ lbs}}$

TABLE 4 THRUST vs. SHP AT BOLLARD

DIAMETER = 12.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
2500	.963	6.67	.902	6.39	.943	6.63	.914	6.72
5000	1.430	9.11	1.303	9.43	1.437	9.28	1.253	9.85
DIAMETER = 13.0 FT								
2500	.797	7.40	.737	6.88	.746	7.27	.747	7.35
5000	1.127	10.56	1.051	10.52	1.117	10.83	1.045	10.82
7500	1.434	12.58	1.306	13.02	1.442	12.83	1.256	13.60
10,000	HI	÷	1.434	14.17	HI	÷	1.444	15.37

DIAMETER = 14.0 FT

2500	.640	7.79	.613	7.44	.614	7.95	.614	7.69
5000	.927	11.84	.869	11.31	.901	11.82	.879	11.91
7500	1.157	14.45	1.070	14.41	1.130	14.82	1.062	14.83
10000	1.372	16.25	[illegible]	16.85	1.307	16.55	1.212	17.47
12500	1.512	[illegible]	[illegible]	[illegible]	1.557	[illegible]	1.338	19.64
15000	HI	÷	1.431	[illegible]	HI	÷	1.475	20.74

TABLE 5 THRUST VS. SHP AT BOLLARD

DIAMETER = 15.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
Shp	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
2500	.531	8.01	.511	7.71	.502	8.0	.508	9.17
5000	.728	12.97	.728	12.02	.737	12.74	.739	12.85
7500	.955	16.13	.894	15.44	.934	16.17	.906	16.26
10,000	1.112	18.51	1.040	18.44	1.103	18.99	1.034	18.95
12,500	1.276	20.41	1.168	20.72	1.260	20.87	1.147	21.45
15,000	1.418	22.05	1.291	22.83	1.422	22.45	1.244	23.82
17,500	HIGH	%	1.387	24.38	HIGH	%	1.322	25.28
20,000	HIGH	%	1.433	25.10	HIGH	%	1.426	27.11

TABLE 6 THRUST VS. SHP AT BOLLARD

DIAMETER = 16.0 FT

Profile Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^3 lbs	P/D	T 10^3 lbs	P/D	T 10^3 lbs	P/D	T 10^3 lbs
2500	(.487)	(9.22)	(.422)	(7.[illegible])	(.405)	(7.47)	(.438)	9.61
5000	.651	13.57	.620	12.58	.623	13.78	.623	13.37
7500	.821	17.57	.762	16.43	.771	17.22	.770	17.44
10,000	.931	20.48	.880	19.58	.915	20.44	.891	20.62
12,500	1.052	22.91	.983	22.59	1.042	23.35	.988	23.29
15,000	1.169	24.96	1.084	24.88	1.150	25.58	1.074	25.64
17,500	1.287	26.60	1.177	27.03	1.272	27.15	1.154	27.99
20,000	1.392	28.09	1.267	28.63	1.350	28.55	1.225	30.23
22,500	1.473	29.72	1.346	30.71	1.425	31.65	1.290	32.22
25,000	Hi	%	1.404	31.[illegible]	Hi	%	1.354	33.89
27,500	Hi	%	Hi	%	Hi	%	1.422	35.05

TABLE 7 THRUST VS SHP AT BOLLARD

DIAMETER: 17.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
2500	(.480)	(11.51)	(.348)	(5.50)	(.325)	(5.29)	(0.37)	12.34
5000	.540	13.76	.531	13.41	.523	14.15	.527	13.95
7500	.641	18.75	.652	17.42	.657	18.11	.659	18.36
10,000	.815	22.20	.755	20.73	.765	21.77	.764	22.03
12,500	.903	24.98	.847	23.52	.871	24.55	.855	25.07
15,000	.988	27.55	.926	26.66	.972	27.78	.935	27.84
17,500	1.071	29.63	1.006	29.37	1.002	30.29	1.002	30.20
20,000	1.158	31.58	1.075	31.47	1.146	32.37	1.067	32.41
22,500	1.246	33.29	1.144	33.48	1.236	33.99	1.127	34.00
25,000	1.329	34.60	1.212	35.47	1.318	35.23	1.182	36.80
27,500	1.403	36.05	1.275	37.23	1.404	36.65	1.233	38.57
30,000	Hi	%	1.464	37.16	Hi	%	1.251	40.79
32,500	Hi	%	Hi	%	Hi	%	1.320	41.37
35,000	Hi	%	Hi	%	Hi	%	1.377	43.77
37,500	Hi	%	Hi	%	Hi	%	(1.425)	(40.25)

TABLE 8 THRUST VS. SHP AT BOLLARD

DIAMETER = 18.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10³ lbs	P/D	T 10³ lbs	P/D	T 10³ lbs	P/D	T 10³ lbs
5000	(.496)	(15.15)	(.494)	(13.64)	(.4[illegible]5)	(13.52)	(.452)	(15.67)
7500	.552	15.78	.561	18.37	.562	[illegible]	.563	18.54
10,000	.697	23.01	.652	21.92	.658	23.48	[illegible]	23.10
12,500	.730	26.96	.727	25.01	.739	26.07	.741	26.72
15,000	.862	29.75	.806	28.16	.818	29.25	.811	29.63
17,500	.926	32.29	.865	30.54	.877	32.22	.878	32.47
20,000	.985	34.70	.927	33.48	.973	34.96	.936	35.02
22,500	1.051	36.68	.987	36.16	1.041	37.25	.957	37.27
25,000	1.116	38.48	1.092	38.32	1.106	37.45	1.036	39.40
27,500	1.152	40.32	1.073	40.20	1.108	41.23	1.053	41.45
30,000	1.247	41.50	1.145	42.13	[illegible]	[illegible]	1.125	43.54
32,500	[illegible]	43.07	1.137	44.01	[illegible]	43.72	1.170	45.63
35,000	1.369	44.41	1.247	45.5[illegible]	1.303	45.14	1.263	47.63
37,500	(1.412)	(45.83)	1.274	47.4[illegible]	(1.330)	(47.16)	1.297	47.51

TABLE 8 THRUST VS. SHP AT BOLLARD

DIAMETER = 13.0

Propeller type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
5000	(.486)	(17.98)	Low	/	Low	/	Low	/
7500	.515	17.78	(.487)	(18.47)	(.470)	(19.31)	(.455)	(20.2[illegible])
10,000	.588	23.62	.571	23.08	.567	24.5[illegible]	.568	23.65
12,500	.676	28.25	.638	26.47	.642	28.26	.643	27.71
15,000	.753	31.86	.691	29.57	.706	31.38	.709	31.49
17,500	.816	34.71	.757	32.42	.764	34.02	.766	34.45
20,000	.869	37.27	.813	35.33	[illegible]	[illegible]	.818	37.16
22,500	.917	39.67	.860	37.81	[illegible]	[illegible]	.869	39.86
25,000	.966	42.01	.904	40.29	[illegible]	[illegible]	.911	42.3[illegible]
27,500	1.013	44.11	.951	42.91	[illegible]	44.64	.957	44.62
30,000	1.061	45.88	.997	45.35	[illegible]	[illegible]	.995	46.71
32,500	1.110	[illegible]	1.036	47.35	[illegible]	[illegible]	1.032	48.71
35,000	1.161	49.4[illegible]	1.077	49.19	[illegible]	[illegible]	1.068	50.66
37,500	1.211	50.75	1.116	[illegible]	[illegible]	[illegible]	1.103	52.60

TABLE 10 THRUST VS SHP AT BOLLARD

T [illegible] = 20 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
7500	(.481)	(22.40)	Low	/	Low	/	Low	%
10,000	.521	24.65	(.496)	(23.31)	(.485)	(24.43)	(.493)	(25.21)
12,500	.577	28.29	.561	27.70	.557	29.41	.558	28.92
15,000	.644	32.66	.615	31.13	.617	33.28	.617	32.23
17,500	.711	36.78	.662	34.03	.669	36.45	.671	36.06
20,000	.766	39.82	.707	36.75	.717	39.16	.720	39.40
22,500	.814	42.49	.759	39.67	.764	41.66	.764	42.17
25000	.856	44.97	.799	42.5	.811	44.15	.804	44.73
27,500	.893	47.25	.837	45.66	.859	46.54	.845	47.34
30,000	.931	49.54	.873	47.34	.906	49.49	.883	49.85
32,500	.968	51.74	.907	49.65	.943	51.95	.918	52.18
35,000	1.005	53.77	.943	52.15	.992	54.32	.950	54.33
37,500	1.042	55.50	.979	54.56	1.032	56.47	.980	56.36

TABLE II THRUST VS. SHP AT BOLLARD

DIAMETER = 21 FT.

Propeller Type	B – 3.50		B – 3.65		B – 4.55		B – 4.70	
SHP	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs
10,000	(·489)	(27.51)	Low	%	Low	%	Low	%
12,500	·517	29.66	(·490)	(27.81)	(·479)	(29.10)	(·459)	(30.38)
15,000	·559	32.93	·543	32.[illegible]	·537	34.09	·539	33.2[illegible]
17,500	·609	36.92	·588	35.86	·587	38.16	·587	36.75
20,000	·662	41.13	·628	38.83	·631	41.56	·632	40.44
22,500	·714	44.92	·665	41.54	·672	44.48	·674	44.06
25,000	·758	47.83	·699	44.01	·709	47.08	·713	47.29
27,500	·797	50.42	·737	46.87	·746	49.50	·748	50.01
30,000	·831	52.90	·773	49.60	·786	51.83	·786	52.52
32,500	·863	55.17	·807	52.26	·819	54.21	·812	54.97
35,000	·892	57.35	·836	54.61	·857	56.53	·844	57.45
37,500	·922	59.54	·864	56.06	·874	59.37	·874	59.85

TABLE 12 THRUST VS SHP AT BOLLARD

DIAMETER 22.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SH.P.	P/D	T 10³ lbs	P/D	T 10³ lbs	P/D	T 10³ lbs	P/D	T 10³ lbs
12,500	(.488)	(33.0)	Low	/	Low	%	Low	%
15,000	.509	34.95	(.476)	(32.00)	(.463)	(33.38)	(.475)	(35.9)
17,500	.538	37.74	.520	36.56	.511	38.50	.516	38.37
20,000	.575	41.23	.559	40.37	.554	42.83	.556	41.44
22,500	.616	45.14	.594	43.13	.593	46.59	.593	44.85
25,000	.659	49.17	.625	46.50	[illegible]	49.77	[illegible]	48.38
27,500	.700	53.00	.655	49.14	.661	52.63	.662	51.80
30,000	.737	55.76	.683	51.61	.691	55.21	.694	55.17
32,500	.770	58.59	.711	54.12	.721	57.61	.723	57.99
35,000	.800	61.01	.740	56.77	.750	59.89	.751	60.54
37,500	.825	63.39	.767	59.40	.778	62.12	.777	62.93

TABLE 13. THRUST VS SHP AT BOLLARD

DIAMETER = 23·0 FT.

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SH.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
17,500	·500	40·72	Low	%	Low	%	Low	%
20,000	·520	42·99	(·4[illegible]4)	(40·51)	(·484)	(42·45)	(·492)	(43·9[illegible])
22,500	·541	45·89	·528	44·67	·521	4[illegible]·13	·525	46·54
25,000	·575	49·28	·559	45·28	·555	51·20	·556	49·53
27,500	·608	53·00	·587	51·41	·586	54·80	·586	52·77
30,000	·641	56·86	·613	54·26	·615	55·41	·615	56·14
32,500	·676	60·66	·638	56·88	·642	60·[illegible]	·643	59·51
35,000	·705	64·10	·661	59·3[illegible]	·662	63·[illegible]4	·660	62·81
37,500	·730	66·85	·683	61·65	·691	66·99	·695	65·95

TABLE 14 THRUST VS SHP AT BOLLARD

DIAMETER = 24.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
20,000	(.491)	47.20	Low	/	Low	/	Low	/
22,500	.505	48.94	Low	/	Low	/	Low	/
25,000	.522	51.23	(.458)	(48.52)	(.487)	(50.85)	(.475)	(52.38)
27,500	.543	54.00	.525	52.47	.517	55.31	.521	54.83
30,000	.566	57.17	.550	55.99	.545	59.32	.547	57.62
32,500	.591	60.63	.571	59.17	.571	62.93	.571	60.64
35,000	.618	64.28	.596	62.06	.595	66.22	.595	63.92
37,500	.646	67.98	.617	64.74	.619	69.22	.619	67.06

TABLE 15 THRUST VS SHP AT BOLLARD

DIAMETER = 25.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
25,000	(.433)	(55.84)	Low	/	Low	/	Low	/
27,500	.509	57.54	Low	/	Low	/	Low	/
30,000	.518	59.68	(.491)	(56.15)	(.480)	(58.61)	(.459)	(61.1)
32,500	.531	62.21	.514	[illegible]	.505	63.07	.511	63.39
35,000	.552	65.15	.536	63.55	.527	67.14	.532	65.87
37,500	.572	68.22	.556	[illegible]	.551	70.94	.552	68.64

TABLE 16 MAX THRUST WITHOUT CAVITATION - AVERAGE DIAMETERS

ARRANGEMENT		CASE	PROPELLER DIA. [FT]	THRUST/SCREW 10^4 LBS.		SHP/SCREW 10^4 HP		TOTAL THRUST 10^4 LBS		TOTAL SHP 10^4 HP		THRUST/SHP LBS/HP	
				B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70
TWIN SCREW		I	16.25	18.4	18.5	0.80	0.76	36.8	37.0	1.60	1.52	23.0	24.4
		II	18.56	25.5	26.2	1.23	1.20	51.0	52.4	2.15	2.40	20.8	21.8
		III	20.88	33.4	34.9	1.63	1.63	66.8	69.8	3.25	3.25	20.35	21.48
TRIPLE SCREW 1:1:1		I	13.50	11.8	12.0	0.53	0.58	35.4	36.0	1.575	1.725	22.5	20.85
		II	15.46	16.0	16.0	0.78	0.73	48.0	48.0	2.325	2.10	20.6	22.80
		III	17.40	22.0	23.0	1.06	1.05	66.0	69.0	3.188	3.15	20.7	21.9
TRIPLE SCREW 1:2:1	CS	I	16.88	19.8	20.4	0.975	0.925	34.5	38.4	1.835	2.025	18.99	17.0
	OS		11.81	7.5	9.0	0.43	0.55						
	CS	II	19.20	27.5	29.0	1.325	1.34	51.3	53.4	2.385	2.492	21.5	21.4
	OS		13.60	11.9	12.2	0.53	0.577						
	CS	III	21.62	35.9	38.0	1.72	1.75	67.7	68.4	3.22	3.15	21.0	21.7
	OS		15.29	15.9	15.2	0.75	0.70						

T.17 COMPARISON A : MAX. THRUST WITHOUT CAVITATION* (LIMIT DIAMETERS)

ARRANGEMENT		CASE	PROP DIA. [FT]	THRUST / SCREW* 10⁴ lbs		SHP / SCREW** 10⁴ HP		TOTAL THRUST 10⁴ lbs		TOTAL SHP 10⁴ HP		THRUST / SHP lbs/HP	
				B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70
TWIN - SCREW		I	18.90	26.2	31.8	1.27	1.47	52.4	63.6	2.54	2.94	20.6	21.6
TWIN - SCREW		II	21.60	35.8	38.0	1.73	1.77	71.6	76.0	3.46	3.54	20.7	21.5
TWIN - SCREW		III	23.00	42.0	44.6	2.00	2.08	84.0	89.2	4.00	4.16	21.0	21.4
TRIPLE - SCREW 1:1:1		I	14.93	14.9	14.2	0.71	0.64	44.7	42.6	2.13	1.92	21.0	22.2
TRIPLE - SCREW 1:1:1		II	17.07	20.3	21.8	0.99	0.99	60.9	65.4	2.97	2.97	20.5	22.0
TRIPLE - SCREW 1:1:1		III	19.20	27.3	28.8	1.32	1.32	81.9	86.4	3.96	3.96	20.7	21.8
TRIPLE SCREW 1:2:1	℄	I	18.56	25.0	30.2	1.21	1.23	47.0	53.2	2.23	2.43	21.1	21.9
TRIPLE SCREW 1:2:1	OBD	I	13.12	11.0	11.5	0.51	0.57						
TRIPLE SCREW 1:2:1	℄	II	21.21	34.3	36.4	1.68	1.69	63.1	65.2	3.12	3.01	20.2	21.7
TRIPLE SCREW 1:2:1	OBD	II	15.00	14.9	14.4	0.72	0.66						
TRIPLE SCREW 1:2:1	℄	III	23.00	42.0	44.6	2.00	2.08	78.0	81.2	3.78	3.72	20.6	21.8
TRIPLE SCREW 1:2:1	OBD	III	16.27	18.0	18.3	0.79	0.82						

* Max. thrust & corresponding dia., without cavitation

** SHP corresponding to the thrust found in (*)

† Burrill's heavily loaded propellers cavitation limit used.

TABLE 16 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-3.50

ARR.											
	SHP TOTAL		15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW		7,500			15,000			22,500		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs		17.3	14.0	—	25.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		34.6	28.0	—	50.4	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW		5,000			10,000			15,000		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs		11.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		33.0	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW		7,500			15,000			22,500		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs		17.4	14.9	—	27.0	—	—	—	—	—
	SHP/SCREW		3,750			7,500			11,250		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs		—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		—	—	—	—	—	—	—	—	—

TABLE 14 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	16.1	14.2	—	25.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	32.2	28.4	—	50.0	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	8.5	—	15.5	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	25.5	—	46.5	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.2	14.8	10.0	26.0	20.5	—	—	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	8.0	—	—	10.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	32.2	—	—	46.0	40.7	—	—	—	—

TABLE 20 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	17.2	14.2	—	26.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	34.4	28.4	—	52.0	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	8.0	—	16.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	24.0	—	48.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	17.5	15.0	—	27.0	—	—	36.0	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	7.5	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	32.5	—	—	—	—	—	—	—	—

TABLE 21 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	17.2	14.4	—	26.01	—	—	33.0	—	—
	TOTAL THRUST 10^4 lbs	34.4	28.8	—	52.02	—	—	66.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	8.0	24.0	16.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	—	—	48.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	18.0	14.8	—	27.6	—	—	33.0	—	—
	SHP/SCREW	3,750			7500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 22 — COMPARISON OF THRUSTS

AHEAD — AVERAGE DIA.

CASE: 11 — PROPELLER TYPE: B-350

SHP TOTAL AT...		50,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	30.8	24.0	—	38.4	—	—	43.5	—	—
	TOTAL THRUST 10^4 lbs	61.6	48.0	—	76.8	—	—	87.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	19.20	—	—	23.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	57.6	—	—	69.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15000			22500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	32.0	25.5	—	40.4	—	—	46.6	—	—
	SHP/SCREW OS	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	13.4	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	58.8	—	—	—	—	—	—	—	—

TABLE 23 COMPARISON OF THRUSTS

AHEAD AVERAGE DIA.

CASE: II PROPELLER TYPE B-3.65

	SHP TOTAL ESP	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	29.0	24.0	—	37.2	—	—	44	—	—
	TOTAL THRUST 10^4 lbs	58.0	48.0	—	74.4	—	—	88	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	18.8	14.8	—	23.5	—	—	27.0	—	—
	TOTAL THRUST 10^4 lbs	56.4	44.4	—	70.5	—	—	81.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	30.0	25.2	—	38.5	—	—	45.8	—	—
	SHP/SCREW OS	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	14.0	—	—	16.4	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	58.0	—	—	71.3	—	—	—	—	—

TABLE 24 COMPARISON OF THRUSTS

AHEAD AVERAGE DIA.

CASE: II PROPELLER TYPE: B-4.55

ARR.										
	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,5000			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.56	15.8	13.0	18.56	15.8	1.30	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	30.2	25.0	—	38.4	—	—	45.0	—	—
	TOTAL THRUST 10^4 lbs	60.4	50.0	—	76.8	—	—	90.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	19.5	—	—	23.6	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	58.5	—	—		—	—	10.8	—	—
TRIPLE SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	31.9	26.2	—	40.2	—	—	47.3		—
1:2:1	SHP/SCREW	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	14.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	54?	—	—	—	—	—	—	—	—

TABLE 25 COMPARISON OF THRUSTS

AHEAD AVERAGE DIA

CASE: 11 PROPELLER TYPE: B-4.70

AHP	SHP TOTAL	30,000			45000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	30.0	25.0	—	38.0	—	—	45.0	—	—
	TOTAL THRUST 10^4 lbs	60.0	50.0	—	76.0	—	—	90.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	18.0	—	—	24.3	—	—	28.0	—	—
	TOTAL THRUST 10^4 lbs	57.0	—	—	72.9	—	—	84.0	—	—
TRIPLE SCREW	SHP/SCREW	15,000			22,500			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	31.0	26.03	—	40.0	32.5	—	47.1	—	—
1:2:1	SHP/SCREW	7500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	14.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	69.0	—	—	—	—	—	—	—	—

TABLE [illegible] COMPARISON OF THRUSTS

AHEAD OPERATION   AVERAGE DIAMETERS

CASE: III   PROPELLER TYPE: B-3.50

ARR.		100	85	70	100	85	70	100	85	70
	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA FT	[illegible]	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	33.4	29.2	—	44.0	36.0	—	52.4	40.5	—
	TOTAL THRUST 10^4 lbs	66.8	58.4	—	88.0	72.0	—	104.8	81.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	22.5	18.0	—	28.5	21.4	—	32.8	—	—
	TOTAL THRUST 10^4 lbs	67.5	54.0	—	85.5	64.2	—	98.4	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,000			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	34.2	30.4	22.2	44.6	37.9	—	54.6	43.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	16.7	12.5	—	20.2	—	—	22.8	—	—
	TOTAL THRUST 10^4 lbs	67.6	55.4	—	85.0	—	—	100.2	—	—

TABLE 27 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	31.8	27.8	21.0	41.6	35.5	—	49.0	41.5	—
	TOTAL THRUST 10^4 lbs	63.6	55.6	42.0	83.2	71.0	—	98.0	83.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	21.0	18.0	—	27.0	22.0	—	32.4	—	—
	TOTAL THRUST 10^4 lbs	63.0	54.0	—	81.0	66.0	—	97.2	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	82.8	28.8	22.8	42.7	36.9	—	51.0	43.2	—
	SHP/SCREW	7,500			11,250			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	15.5	13.0	—	19.9	15.0	—	23.0	—	—
	TOTAL THRUST 10^4 lbs	63.8	54.8	—	82.5	66.9	—	97.0	—	—

TABLE [illegible] COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	[illegible]	28.8	—	43.8	36.4	—	52.0	41.2	—
	TOTAL THRUST 10^4 lbs	68.0	57.6	—	87.6	72.8	—	104.0	82.4	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	22.0	18.8	—	28.0	—	—	33.0	—	—
	TOTAL THRUST 10^4 lbs	66.0	56.4	—	84.0	—	—	99.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	36.0	30.0	22.5	45.3	38.0	—	53.5	44.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	16.8	12.8	—	20.7	—	—	23.4	—	—
	TOTAL THRUST 10^4 lbs	69.6	55.6	—	86.7	—	—	100.3	—	—

TABLE 29 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	33.3	28.9	22.04	43.2	36.4	—	52.0	42.8	—
	TOTAL THRUST 10^4 lbs	66.6	57.8	44.08	86.4	72.8	—	104.0	85.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	22.03	18.02	—	28.3	23.0	—	33.2		
	TOTAL THRUST 10^4 lbs	66.09	54.06	—	84.9	69.0	—	99.6		
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	34.8	29.9	23.5	44.5	38.0	—	53.5	44.8	—
	SHP/SCREW	7,500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	16.0	13.0	—	20.4	—	—	24.0	—	—
	TOTAL THRUST 10^4 lbs	66.8	55.9	—	85.3	—	—	101.5	—	—

TABLE 30 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-3.50

	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.90	16.05	13.23	18.90	1605	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs	20.0	17.6	12.8	31.2	25.2	H	39.2	H	H
	TOTAL THRUST 10^4 lbs	40.0	35.2	25.6	62.4	50.4	H	78.4	H	H
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.69	10.45
	THRUST PER SCREW 10^4 lbs	12.4	9.8	H	18.0	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	37.2	29.4	H	54.0	H	H	H	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.78	12.99	18.56	15.78	12.99	1856	15.78	12.99
	THRUST PER SCREW 10^4 lbs	19.4	16.8	12.0	30.6	24.00	H	38.2	H	H
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.12	11.16	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs	9.2	H	H	12.4	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	37.8	H	H	55.4	H	H	H	H	H

H STANDS FOR TOO HIGH P/D RATIO, OR TOO SMALL DIAMETER

TABLE 31 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-3.65

	SHP TOTAL ARR.		15,000			30,000			45,000	
TWIN SCREW	SHP/SCREW		7,500			15,000			22,500	
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	18.90	16.05	13.23	18.90	16.05	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs		18.2	16.0	13.50	29.20	24.8	H	37.6	30.6	H
	TOTAL THRUST 10^4 lbs		36.4	32.0	27.0	58.4	49.6	H	75.2	61.2	H
TRIPLE SCREW 1:1:1	SHP/SCREW		5,000			10,000			15000	
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.69	10.45
	THRUST PER SCREW 10^4 lbs		11.4	10.00	H	18.0	H	H	H	H	H
	TOTAL THRUST 10^4 lbs		34.2	30.00	H	54.0	H	H	H	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW		7,500			15,000			22,500	
		%	100	85	70	100	85		100	85	70
	DIA.	FT	18.56	15.78	12.99	18.56	15.78	12.99	18.56	15.78	12.99
	THRUST PER SCREW 10^4 lbs		L	15.6	12.8	29.2	23.6	H	41.6	H	H
	SHP/SCREW										
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	13.12	11.15	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs		9.2	H	H	13.4	H	H	H	H	H
	TOTAL THRUST 10^4 lbs		H	H	H	56.0	H	H	H	H	H

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 32 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER.

CASE: I PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	15,000			30000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	18.90	16.05	13.23	18.90	16.05	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs	L	17.2	13.2	30.8	25.8	H	39.6	H	H
	TOTAL THRUST 10^4 lbs	—	34.4	26.4	61.6	51.6	H	79.2	H	H
TRIPLE SCREW 1:1:1	SHP/SCREW	5000			10,000			15000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.66	10.45
	THRUST PER SCREW 10^4 lbs	12.4	10.0	H	18.8	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	37.2	30.0	H	56.4	H	H	H	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.78	12.99	18.56	15.78	12.99	18.56	15.78	12.99
	THRUST PER SCREW 10^4 lbs	L	16.8	H	30.4	24.4	H	38.4	H	H
	SHP/SCREW	3,750			7500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	13.12	11.15	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs	9.2	H	H	12.8	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	H	H	55.0	H	H	H	H	H

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 33 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-4.70

AGR.	SHP TOTAL	15,000			30000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.90	16.05	13.23	18.90	16.15	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs	L	17.2	13.6	30.2	26.0	H	38.8	32.2	H
	TOTAL THRUST 10^4 lbs	—	34.4	27.2	60.4	52.0	—	77.6	64.4	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.69	10.45
	THRUST PER SCREW 10^4 lbs	12.00	14.0	H	18.0	H	H	22.8	H	H
	TOTAL THRUST 10^4 lbs	36.0	30.0	—	54.0	—	—	68.4	—	—
TRIPLE SCREW	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.78	12.99	18.56	15.78	12.99	18.56	15.78	12.95
	THRUST PER SCREW 10^4 lbs	L	16.4	H	30.0	26.0	H	38.0	H	H
1:2:1	SHP/SCREW	3,750			7,500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	13.12	11.15	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs	9.6	H	H	13.2	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	—	—	56.4	—	—	—	—	—

L: P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE [illegible] COMPARISON O. THRUSTS

[illegible] LIMIT DIAMETER

CASE: II PROPELLER TYPE: B-3.50

	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	34.2	30.4	22.4	44.8	37.2	H	54.4	42.8	H
	TOTAL THRUST 10^4 lbs	68.4	60.8	44.8	89.6	74.4	—	108.8	85.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	23.0	17.2	H	27.6	H	H	31.6	H	H
	TOTAL THRUST 10^3 lbs	69.0	51.6	—	82.8	—	—	94.8	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	34.0	29.9	H	45.6	36.6	H	53.6	41.6	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	16.00	H	H	19.6	H	H	22.0	H	H
	TOTAL THRUST 10^4 lbs	66.0	—	—	84.8	—	—	97.6	—	—

H = P/D HIGHER THAN 1.40

TABLE [illegible] COMPARISON OF [illegible]

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: B.365

	SHP TOTAL / ARR.	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	32.4	28.4	23.0	47.4	36.4	H	50.8	42.8	H
	TOTAL THRUST 10^4 lbs	64.8	56.8	46.0	94.8	72.8	—	101.6	85.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	20.4	17.6	H	26.4	21.2	H	31.4	H	H
	TOTAL THRUST 10^4 lbs	61.2	52.8	—	79.2	63.6	—	94.2	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	32	28	21.2	42.4	33.2	H	50.4	42.5	H
	SHP/SCREW	7500			11250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	15.6	12.4	H	19.6	H	H	22.8	H	H
	TOTAL THRUST 10^4 lbs	63.2	52.8	—	81.6	—	—	96.0	—	—

TABLE 36 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	L	30.0	22.4	45.2	37.6	H	53.6	43.6	H
	TOTAL THRUST 10^4 lbs	—	60.0	44.8	90.4	75.2	H	107.2	87.2	H
TRIPLE SCREW 1:1:1	SHP/SCREW									
	DIA. %	100	85	70	100	85	70	100	85	70
	FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	21.6	18.0	H	27.6	H	H	32.4	H	H
	TOTAL THRUST 10^4 lbs	64.8	54.0	H	82.8	H	H	97.2	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	34.8	29.2	H	44.8	36.8	H	52.4	42.4	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	16.4	H	H	20.4	H	H	22.4	H	H
	TOTAL THRUST 10^4 lbs	67.6	—	—	85.6	—	—	97.2	—	—

H = P/D HIGHER THAN 1.40

TABLE 37 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: B-4.70

	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	34.6	30.3	24.0	44.2	37.6	H	54.26	44.57	H
	TOTAL THRUST 10^4 lbs	68.2	60.6	48.0	88.4	75.2	—	108.52	89.14	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	22.1	18.1	H	27.6	H	H	32.5	H	H
	TOTAL THRUST 10^4 lbs	66.3	54.3	—	82.8	—	—	97.5	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	33.6	29.7	23.5	44.0	31.53	H	53.15	43.61	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	16.2	13.2	H	20.00	H	H	23.82	H	H
	TOTAL THRUST 10^4 lbs	66.0	56.1	—	84.0	—	—	100.79	—	—

H = P/D HIGHER THAN 1.40

TABLE 38 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B-3.50

	SHP TOTAL APR.	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.66	25.20	45.88	41.24	H	56.85	48.09	H
	TOTAL THRUST 10^4 lbs	—	75.32	50.4	91.76	82.48	—	113.70	96.18	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	23.7	21.0	15.20	32.22	25.73	H	37.81	29.17	H
	TOTAL THRUST 10^4 lbs	71.1	63.0	46.60	96.66	77.19	—	113.43	87.51	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.66	25.20	45.88	41.24	H	56.85	48.09	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	—	13.80	H	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	6076	—	—	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 39 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B-3.65

SHP TOTAL / APP.		30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	30.37	25.11	46.67	39.01	31.05	54.20	46.35	H
	TOTAL THRUST 10^4 lbs	—	60.74	50.22	93.34	78.02	62.10	108.40	92.70	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	23.2	20.01	15.65	29.73	25.62	H	35.60	29.81	H
	TOTAL THRUST 10^4 lbs	69.6	60.03	46.95	89.19	76.86	—	106.98	89.43	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	30.37	25.11	46.67	39.01	31.05	54.20	46.35	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	L	16.00	H	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	62.37	—	—	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 40 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.52	25.84	47.12	40.51	H	58.0	48.42	H
	TOTAL THRUST 10^4 lbs	—	65.04	51.68	94.24	81.02	—	116.0	96.84	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	24.6	20.83	H	31.81	26.40	13.51	37.07	29.72	H
	TOTAL THRUST 10^4 lbs	73.8	62.49	—	95.43	79.2	40.53	111.21	89.16	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.52	25.84	47.12	40.51	H	58.0	48.42	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	—	—	—	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	—	—	H	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 41 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B-4.70

ARR	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	31.97	25.85	46.54	41.04	37.50	56.13	48.53	H
	TOTAL THRUST 10^4 lbs	—	63.94	51.7	93.08	82.08	65.00	102.26	97.06	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	23.8	21.05	16.53	31.73	26.33	H	37.58	30.91	H
	TOTAL THRUST 10^4 lbs	71.4	63.15	49.59	95.19	78.99	—	112.74	92.73	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	31.97	25.85	46.54	41.04	37.50	56.13	48.53	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	—	H	H	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	H	H

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 42 COMPARISON C

MAX SHP FOR NO-CAVITATION (ALL ARRANGEMENTS)

CASE	AVERAGE DIAMETERS		LIMIT DIAMETERS	
	B-3.65	B-4.70	B-3.65	B-4.70
I	15,750 B	15,200 A	21,300 B	19,200 B
II	23,250 B	21,000 B	29,700 B	29,700 B
III	31,875 B	31,500 B,C	37,800 C	37,200 C

A - TWIN SCREW ARR. STARTS FIRST TO CAVITATE

B: TRIPLE SCREW 1:1:1 -"- -"- -"- -"-

C: TRIPLE SCREW 1:2:1 -"- -"- -"- -"-

TABLE 43 CALCULATION OF $[T_{ASTERN}/T_{AHEAD}]$

PROPELLER TYPE	B-3.50	B-3.65	B-4.55	B-4.70
$l_{0.6R}/D$	.370	.481	.383	.501
$l_{0.7R}/l_{0.6R}$	.9919	.9919	.9808	.9808
$l_{0.7R}/D$	.369	.478	.376	.491
$S_{0.7R}/D$	.0171	.0171	.0156	.0156
$S_{0.7R}/l_{0.7R}$	.0465	.0358	.0415	.0317
$h_{0.7R}/l_{0.7R}$	.0233	.0179	.0208	.0159
$(C_T/C_Q)_{AHEAD}$	6.95	6.78	6.87	6.71
$(C_T/C_Q)_{ASTERN}$	5.44	5.61	5.51	5.68
T_{ASTERN}/T_{AHEAD}	.782	.827	.802	.846

Legend:

l = chord length, ft.

D = propeller diameter, ft.

S: blade thickness, ft

h: blade camber, ft

C_T: thrust coeff.

C_Q: torque coeff.

T: thrust, lbs

TABLE 44 — COMPARISON OF THRUSTS

ASTERN OPERATION — AVERAGE DIAMETERS

CASE: I — PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	13.8	11.0	—	20.1	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	27.6	22.0	—	40.2	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	8.5	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	25.5	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	14.1	11.8	—	21.0	—	—	25.2	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	6.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	26.1	—	—	—	—	—	—	—	—

TABLE 45 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	26.1	22.9	17.9	34.9	29.0	—	41.0	34.1	—
	TOTAL THRUST 10^4 lbs	52.2	45.8	35.8	69.8	58.0	—	82.0	68.2	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	17.3	14.8	—	22.5	18.2	—	26.9	—	—
	TOTAL THRUST 10^4 lbs	51.9	44.4	—	67.5	54.6	—	80.7	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.5	21.62	18.4	15.5	21.62	18.4	15.5
	THRUST PER SCREW 10^4 lbs	27.1	23.6	19.0	35.5	30.4	—	42.1	35.9	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	12.9	10.1	—	16.4	12.1	—	19.4	—	—
	TOTAL THRUST 10^4 lbs	52.9	43.8	—	68.5	54.6	—	80.9	—	—

TABLE 46 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B 4.55

	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	14.0	11.3	—	21.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	28.0	22.6	—	42.0	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	9.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	27.0	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	14.3	12.2	—	22.0	—	—	26.8	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 47. COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	14.9	12.2	—	22.0	—	—	27.6	—	—
	TOTAL THRUST, 10^4 lbs	29.8	24.4	—	44.0	—	—	55.2	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	9.6	—	—	14.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	28.8	—	—	[illegible]	—	—	—	—	—
TRIPLE SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	15.2	12.9	—	23.0	18.6	—	29.0	—	—
1:2:1	SHP/SCREW	3,750			7500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 48 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: II PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	24.0	19.0	—	29.9	—	—	34.1	—	—
	TOTAL THRUST 10^4 lbs	48.0	38.0	—	59.8	—	—	68.2	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	15.2	—	—	18.1	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	45.6	—	—	543	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	25.0	20.2	—	31.7	—	—	36.2	—	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	10.2	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	45.4	—	—	—	—	—	—	—	—

TABLE 49 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: II PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	23.8	20.1	—	30.5	25.0	—	36.0	—	—
	TOTAL THRUST 10^4 lbs	47.6	40.2	—	61.0	50.0	—	72.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	15.4	12.0	—	19.5	—	—	22.7	—	—
	TOTAL THRUST 10^4 lbs	46.2	36.0	—	58.5	—	—	68.1	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.45	19.20	16.32	13.45
	THRUST PER SCREW 10^4 lbs	24.8	21.0	—	31.4	26.0	—	37.9	—	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	11.0	—	—	13.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	46.8	—	—	57.4	—	—	—	—	—

TABLE 50 — COMPARISON OF THRUSTS

ASTERN OPERATION — AVERAGE DIAMETERS

CASE: II — PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	24.6	19.9	—	31.0	—	—	35.9	—	—
	TOTAL THRUST 10^4 lbs	49.2	39.8	—	62.0	—	—	71.8	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	15.9	—	—	19.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	47.7	—	—	57.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	25.6	21.2	—	32.0	—	—	37.8	-	-
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	11.1	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	47.8	—	—	—	—	—	—	—	—

TABLE 51 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: II PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45000			60000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	25.8	21.4	—	32.5	26.5	—	38.1	—	—
	TOTAL THRUST 10^4 lbs	51.6	42.8	—	65.0	53.0	—	76.2	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82			
	THRUST PER SCREW 10^4 lbs	16.6	13.4	—	20.8	—	—	24.0	—	—
	TOTAL THRUST 10^4 lbs	49.8	40.2	—	62.4		—	72.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	26.5	22.2	—	34.0	27.9	—	39.9	32.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.1	—	—	15.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs.	50.7	—	—	64.0	—	—	—	—	—

TABLE 52 — COMPARISON OF THRUSTS

ASTERN OPERATION — AVERAGE DIAMETERS

CASE: III — PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	25.9	23.0	—	34.4	28.0	—	41.0	32.0	—
	TOTAL THRUST 10^4 lbs	51.8	46.0	—	68.8	56.0	—	82.0	64.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	17.6	14.1	—	22.2	—	—	25.5	—	—
	TOTAL THRUST 10^4 lbs	52.8	42.3	—	66.6	—	—	76.5	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	26.8	23.8	—	35.2	29.8	—	42.8	34.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	13.0	—	—	16.0	—	—	17.9	—	—
	TOTAL THRUST 10^4 lbs	52.8	—	—	67.2	—	—	78.6	—	—

TABLE 53 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	13.4	11.5	—	20.9	16.0	—	25.9	—	—
	TOTAL THRUST 10^4 lbs	26.8	23.0	—	41.8	32.0	—	51.8	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	8.9	—	—	12.8	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	26.7	—	—	38.4	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	13.8	12.0	—	21.7	17.1	—	27.5	—	—
	SHP/SCREW	3,750			7500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 54 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	27.2	23.7	—	35.1	29.3	—	41.3	33.8	—
	TOTAL THRUST 10^4 lbs	54.4	47.4	—	70.2	58.6	—	82.6	67.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	18.0	14.7	—	23.0	—	—	27.0	—	—
	TOTAL THRUST 10^4 lbs	54.0	44.1	—	69.0	—	—	81.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	28.0	24.4	18.2	36.6	30.9	—	43.2	35.5	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	13.2	10.2	—	16.5	—	—	18.4	—	—
	TOTAL THRUST 10^4 lbs	54.4	44.8	—	69.6	—	—	80.0	—	—

TABLE 55 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	28.0	24.9	19.0	37.0	31.1	—	44.2	36.5	—
	TOTAL THRUST 10^4 lbs	56.0	49.8	38.0	74.0	62.2	—	88.4	73.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	18.9	15.9	—	24.0	19.8	—	28.3	—	—
	TOTAL THRUST 10^4 lbs	56.7	47.7	—	72.0	59.4	—	84.9	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	29.5	25.6	20.2	37.6	32.4	—	45.8	38.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	14.0	11.4	—	17.7	—	—	20.4	—	—
	TOTAL THRUST 10^4 lbs	57.5	48.4	—	73.0	—	—	86.6	—	—

TABLE 56 COMPARISON OF THRUSTS

AHEAD OPERATION - COMPROMISE PROPELLER

CASE: I PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL		15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW		7,500			15,000			22,500		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs		15.7	12.4	—	22.6	—	—	27.5	—	—
	TOTAL THRUST 10^4 lbs		31.4	24.8	—	45.2	—	—	55.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW		5,000			10,000			15,000		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs		9.8	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		29.4	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW		7,500			15,000			22,500		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs		16.0	13.2	—	24.0	—	—	28.9	—	—
	SHP/SCREW		3,750			7,500			11,250		
	DIA.	%	100	85	70	100	85	70	100	85	70
		FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs		—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		—	—	—	—	—	—	—	—	—

TABLE 57 COMPARISON OF THRUSTS

AHEAD OPERATION COMPROMISE PROPELLER

CASE: I PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	15.0	12.9	—	23.0	—	—	28.5	—	—
	TOTAL THRUST 10^4 lbs	30.0	29.8	—	46.0	—	—	57.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	10.00	—	—	14.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	30.0	—	—	42.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	15.5	13.1	—	23.8	19.0	—	29.9	—	—
	SHP/SCREW	3,750			7,500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 58 — COMPARISON OF THRUSTS

AHEAD OPERATION — COMPROMISE PROPELLER

CASE: I — PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	15.9	12.9	—	23.3	—	—	28.0	—	—
	TOTAL THRUST 10^4 lbs	31.8	25.8	—	46.6	—	—	56.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	10.0	—	—	14.1	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	30.0	—	—	42.3	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.3	13.6	—	24.5	—	—	30.0	—	—
	SHP/SCREW	3,750			7500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 58 COMPARISON OF THRUSTS

AHEAD OPERATION COMPROMISE PROPELLER

CASE: I PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	16.2	13.8	—	24.1	—	—	30.2	—	—
	TOTAL THRUST 10^4 lbs	32.4	27.6	—	48.2	—	—	60.4	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.8	11.48	9.45	13.8	11.48	9.45
	THRUST PER SCREW 10^4 lbs	10.6	—	—	15.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	31.8	—	—	45.6	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.6	14.2	—	25.1	20.1	—	31.5	—	—
	SHP/SCREW	3,750			7,500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 60 COMPARISON OF THRUSTS

AHEAD COMPROMISE

CASE II PROPELLER TYPE: B-350

ARR.		30,000			45,000			60,000		
	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.7	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	27.2	21.5	—	34.0	—	—	37.0	—	—
	TOTAL THRUST 10^4 lbs	54.4	43.0	—	68.0	—	—	73.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	17.0	—	—	20.3	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	51.0	—	—	60.9	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	28.3	22.9	—	35.9	27.6	—	41.2	—	—
	SHP/SCREW OS	7500			11250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.52	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.1	—	—	—					
	TOTAL THRUST 10^4 lbs	52.5	—							

TABLE 61 COMPARISON OF THRUSTS

ANGAD COMPROMISE

CASE: 11 PROPELLER TYPE:

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.56	15.8	13.0	13.56	15.8	13.0	13.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	26.1	22.0	—	33.8	27.2	—	40.0	—	—
	TOTAL THRUST 10^4 lbs	52.2	44.0	—	67.6	54.4	—	80.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	17.1	13.2	—	21.5	---	---	24.8	—	—
	TOTAL THRUST 10^4 lbs	51.3	39.6	—	64.5	—	—	74.4	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	27.2	23.1	—	35.0	23.6	—	41.8	—	—
	SHP/SCREW OS	7500			11250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.7	—	—	14.8	---	---	—	---	---
	TOTAL THRUST 10^4 lbs	51.6	[illegible]	[illegible]	64.6	---				---

TABLE 62 COMPARISON OF THRUSTS

AHEAD COMPROMISE

CASE: II PROPELLER TYPE:

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	27.4	22.1	—	34.9	—	—	40.3	—	—
	TOTAL THRUST 10^4 lbs	54.8	44.2	—	69.8	—	—	80.6	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	17.5	—	—	21.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	52.5	—	—	63.6	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	16.44
	THRUST PER SCREW 10^4 lbs	28.8	23.5	—	36.1	28.0	—	42.9	—	—
	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.2	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	53.2	—	—	—	—	—	—	—	—

TABLE 6.5

BHEAD

CASE: II

COMPARISON OF THRUSTS

COMPROMISE

PROPELLER TYPE: B-4.7

	SHP TOTAL APP.	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.5	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	28.0	23.5	—	35.9	29.0	—	41.7	—	—
	TOTAL THRUST 10^4 lbs	56.0	47.0	—	71.8	58.0	—	83.8	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	18.0	14.6	—	22.8	—	—	26.2	—	—
	TOTAL THRUST 10^4 lbs	54.0	43.8	—	68.4	—	—	78.6	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	29.0	24.2	—	37.1	30.6	—	43.8	—	—
	SHP/SCREW OS	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	13.3	—	—	16.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	55.6	—	—	69.5	—	—	—	—	—

TABLE 64 COMPARISON OF THRUSTS

STERN COMPROMISE

CASE: III PROPELLER TYPE: R-350

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	29.6	26.0	—	39.2	31.9	—	46.5	36.0	—
	TOTAL THRUST 10^4 lbs	59.2	52.0	—	78.4	63.8	—	93.0	72.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	20.1	16.0	—	25.1	—	—	29.0	—	—
	TOTAL THRUST 10^4 lbs	60.3	48.0	—	75.3	—	—	87.0	—	—
TRIPLE SCREW	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	30.2	27.0	20.0	40.0	33.8	---	48.2	38.8	---
1:2:1	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	14.4	11.5	—	18.0	---		20.2	---	---
	TOTAL THRUST 10^4 lbs	59.0	50.0	—	76.0			88.6	---	---

TABLE 65 COMPARISON OF THRUSTS

STERN COMPROMISE

CASE: III PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.58	17.8	14.65	20.58	17.8	14.65	20.58	17.8	14.65
	THRUST PER SCREW 10^4 lbs	29.0	25.0	19.6	37.8	32.3	—	45.0	38.0	—
	TOTAL THRUST 10^4 lbs	58.0	50.0	39.2	75.6	64.6	—	90.0	76.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	19.2	16.1	—	24.6	20.1	—	29.1	—	—
	TOTAL THRUST 10^4 lbs	57.6	48.3	—	73.8	60.3	—	87.3	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	30.0	26.0	21.0	39.0	33.1	—	46.2	39.7	—
	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	14.3	11.2	—	18.2	13.6	—	21.2	—	—
	TOTAL THRUST 10^4 lbs	58.6	48.4	—	75.4	60.4	—	88.6	—	—

TABLE 66 COMPARISON OF THRUSTS

STERN COMPROMISE

CASE: III PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	65	70	100	65	70	100	35	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	30.7	26.0	—	39.8	33.0	—	46.8	37.5	—
	TOT. THRUST 10^4 lbs	61.4	52.0	—	79.6	66.0	—	93.6	75.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	35	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	20.0	16.6	—	25.6	19.9	—	30.0	—	—
	TOTAL THRUST 10^4 lbs	60.0	49.8	—	76.8	57.7	—	10.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	31.3	27.0	20.3	41.0	34.8	—	18.4	40.0	—
	SHP/SCREW OS	7500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	15.0	11.3	—	18.6	—	—	20.5		
	TOTAL THRUST 10^4 lbs	61.3	47.6	—	78.2	—	—	89.1	—	—

TABLE 67 — COMPARISON OF THRUSTS

STERN — COMPRMISE

CASE III — PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	30.5	27.0	21.0	40.0	34.0	—	48.0	40.0	—
	TOTAL THRUST 10^4 lbs	61.0	54.0	42.0	80.0	68.0	—	96.0	80.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	20.5	17.0	—	26.4	21.2	—	31.0	—	—
	TOTAL THRUST 10^4 lbs	61.5	51.0	—	79.2	63.6	—	93.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	32.0	27.9	22.0	41.0	35.5	—	49.6	41.6	—
	SHP/SCREW OS	7500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	15.1	12.6	—	19.2	—	—	22.2	—	—
	TOTAL THRUST 10^4 lbs	62.2	53.1	—	79.4	—	—	94.0	—	—

TABLE 68 SAMPLE CALCULATION

EFFICIENCY AT SPEED OF ADVANCE OF 1 KNOT

Taking case I, twin screw arrangement - we define the diameter of the screws

$D = 16.25$ ft. - for average D_{max}. (Table 1)

If we choose $SHP_{TOTAL} = 15000$ - we define the pitch-ratio used for this arrangement at bollard condition.

From table 74 $P/D = 0.790$

$$\frac{SHP}{screw} = \frac{15000}{2} = 7500$$

$$(a)\quad J = \frac{V_a}{nD} = \frac{1\,\text{knot} \cdot 1.689\,\frac{ft/sec}{knot}}{2\,\text{rps} \cdot 16.25\,ft} = 0.0468$$

We found in table 3 that:

$$(b)\quad K_Q = 43.97\,\frac{SHP}{n^3 D^5}$$, so we calculate now:

$$K_Q = \frac{43.97 \times 7500}{2^3 \cdot (16.25)^5} = 0.0367$$

But for the above J and P/D we read from Henschke's diagram that

$K_Q = 0.0363$

We must change the n so that the 2 values of K_Q will be equal.

For $n = 121$ rpm, $K_Q = 0.0356$, by equation (b)

TABLE 69. SAMPLE CALCULATION (cont'd)

Interpolation of n values in order to get equal K_Q from calculation and graph gives that equilibrium is reached at, $n = 120.27 \sim 120$ rpm.

Conclusion. As equilibrium rpm is very close to 120 rpm, we shall assume that all propellers work at 120 at a speed of advance of one knot, the same as in the bollard condition.

For $J = 0.0468$, $P/D = 0.79$, we find from Henschke's diagram that

$$\eta_0 = \text{open water efficiency} = 6.\%$$

In order to find the propulsive efficiency, we must calculate the hull efficiency η_H, as $\eta_P = \eta_0 \, \eta_H \, \eta_R$.

We assume $\eta_R = 1.0$ for all screws.

For the calculation of η_H, the following values of wake fraction and thrust deduction were assumed:

screw	wake fraction (w)	thrust deduction (t)
center	0.04	0.03
outboard	0.10	0.10

TABLE 70 SAMPLE CALCULATION (cont'd)

$$\eta_{H_i} = \frac{1-t_i}{1-w_i}$$ can be found for each screw

$$\eta_{H_{cs}} = \frac{1-0.03}{1-0.04} = \frac{0.97}{0.96}$$ (center screw)

$$\eta_{H_{o.s}} = \frac{1-0.10}{1-0.10} = \frac{0.90}{0.90} = 1$$ (out board screw)

For the combination of screws in the different arrangements, we use

$$\eta_{H_{TOTAL}} = \frac{1}{\sum \frac{SHP_i}{SHP_{TOTAL}} \frac{1}{\eta_{H_i}}}$$

(a) Twin Screw

$$\eta_{H_{total}} = \frac{1}{\frac{1}{2}\cdot 1 + \frac{1}{2}\cdot 1} = 1.00$$

(b) Triple screw 1:1:1

$$\eta_{H_{total}} = \frac{1}{\underbrace{\frac{1}{3}\,\frac{0.96}{0.97}}_{c.s} + \underbrace{2\cdot\frac{1}{3}\cdot 1}_{o.s}} = \frac{3}{2.991} = 1.003 \sim 1.0$$

(c) Triple Screw 1:2:1

$$\eta_{H_{total}} = \frac{1}{\frac{1}{2}\cdot\frac{0.96}{0.97} + 2\times\frac{1}{4}\cdot 1} = \frac{2}{1.991} = 1.0045 \sim 1.0$$

Conclusion As all η_H are close to unity we can use $\eta_p = \eta_o$ for all arrangements

TABLE 71

Efficiency at V_a = 1 knot (n = 120 RPM) (AVERAGE DIA.)

ARR.	CASE	DIA. [ft], J	SHP max TOTAL	B-3.50 P/D	B-3.50 η_p %	B-3.65 P/D	B-3.65 η_p %	B-4.55 P/D	B-4.55 η_p %	B-4.70 P/D	B-4.70 η_p %
TWIN SCREW	I	16.25'	15000	.730	7.2	.730	7.1	.740	7.7	.741	7.6
		.0520	30000	1.115	5.1	1.042	5.7	1.106	6.0	1.036	5.9
			45000	H	—	1.294	4.8	H	—	1.247	4.8
	II	18.56	30,000	.801	6.8	.741	6.2	.751	6.6	.752	6.6
		.0455	45,000	.971	5.6	.910	5.2	.952	5.4	.921	5.7
			60,000	1.135	4.5	1.057	4.8	1.124	5.2	1.050	5.0
	III	20.88'	30,000	.576	6.6	.551	6.6	.546	7.3	.548	7.2
		.0404	45,000	.726	6.0	.674	5.9	.682	6.4	.684	6.3
			60,000	.843	5.2	.785	5.0	.795	5.7	.791	5.6
TRIPLE SCREW (1:1:1)	I	13.50'	15,000	1.015	6.7	.953	7.0	1.003	7.5	.958	7.3
		.0626	30,000	H	—	1.369	5.2	H	—	1.312	5.5
			45,000	H	—	H	—	H	—	H	—
	II	15.46'	30,000	1.023	5.9	.961	6.1	1.012	6.5	.965	6.4
		.0546	45,000	1.300	4.7	1.168	5.3	1.287	5.4	1.163	5.4
			60,000	H	—	1.372	4.7	H	—	1.321	4.8
	III	17.40'	30,000	.767	6.9	.708	6.8	.718	7.2	.721	7.1
		.0485	45,000	.933	5.7	.871	5.8	.907	6.0	.884	6.1
			60,000	1.081	5.0	1.014	5.2	1.072	5.7	1.010	5.5
CENTER SCREW (1:2:1)	I	16.88'	15,000	.711	7.5	.663	7.5	.669	7.8	.672	7.8
		.0500	30,000	1.005	5.6	.944	5.6	.992	6.2	.950	6.0
			45,000	1.273	4.4	1.166	5.0	1.258	5.2	1.145	5.0
	II	19.20'	30,000	.731	6.9	.678	6.6	.687	6.8	.690	6.9
		.0440	45,000	.895	5.6	.839	5.4	.860	5.9	.846	5.9
			60,000	1.032	4.8	.919	5.0	1.026	5.4	.972	5.2
	III	21.62	30,000	.524	7.2	.501	7.0	.490	—	.498	7.6
		.0391	45,000	.650	6.1	.622	6.0	.622	6.5	.622	6.5
			60,000	.773	5.6	.713	5.3	.723	5.7	.726	5.8
OUTBOARD SCREW (1:2:1)	I	11.81'	15,000	1.269	6.6	1.163	6.9	1.253	7.2	1.142	7.0
		.0715	30,000	H	—	H	—	H	—	H	—
			45,000	H	—	H	—	H	—	H	—
	II	13.60'	30,000	1.260	5.6	1.155	6.0	1.243	6.3	1.135	6.0
		.0621	45,000	H	—	H	—	H	—	1.363	—
			60,000	H	—	H	—	H	—	H	—
	III	15.29'	30,000	.912	5.7	.855	6.4	.882	7.0	.864	6.9
		.0552	45,000	1.127	5.5	1.051	[illegible]	1.117	6.1	1.04[illegible]	6.0
			60.000	1.244	4.7	1.22[illegible]	[illegible]	1.335	5.3	1.10[illegible]	5.3
TRIPLE SCREW (1:2:1) COMBINED	I	16.88' / 11.81'	15,000	—	7.0	—	7.2	—	7.5	—	7.4
			30,000	—	—	—	—	—	—	—	—
			45,000	—	—	—	—	—	—	—	—
	II	19.20' / 13.60'	30,000	—	6.2	—	[illegible]	—	6.6	—	6.4
			45,000	—	—	—	—	—	—	—	—
			60,000	—	—	—	—	—	—	—	—
	III	21.62' / 15.29'	30,000	—			[illegible]	—	—	—	[illegible]
			45,000	—			[illegible]	—	[illegible]	—	[illegible]
			60,000	—			[illegible]	—	[illegible]	—	[illegible]

TABLE 72 PROPULSIVE EFFICIENCY AT SPEED OF ADVANCE OF A KNOT

N = 120 RPM (LIMIT DIAMETERS)

ARR.	CASE	DIA., FT / J (ADV. RATIO)	SHP max TOTAL	B-3.50 P/D	B-3.50 η_p [%]	B-3.65 P/D	B-3.65 η_p %	B-4.55 P/D	B-4.55 η_p %	B-4.70 P/D	B-4.70 η_p %
TWIN SCREW	I	18.90 / .0446	15000	.520	7.8	.495	L	L	—	.492	—
			30000	.764	6.2	.705	6.2	.715	7.0	.718	6.25
			45000	.929	5.4	.871	5.1	.903		.881	5.3
	II	21.60 / .0390	30,000	.525	7.0	.502	7.0	.492	L	.499	7.0
			45,000	.652	5.9	.621	5.9	.624	6.5	.624	6.0
			60,000	.775	5.5	.715	5.0	.725	6.0	.728	5.0
	III	23.0 / .0367	30,000	L	—	L	—	L	-	L	—
			45,000	.546	6.0	.528	6.0	.521	7.5	.525	6.3
			60,000	.641	5.3	.613	5.2	.615	6.4	.615	5.5
TRIPLE SCREW 1:1:1	I	14.93 / .0565	15,000	.797	7.5	.737	7.5	.747	8.0	.748	7.6
			30,000	1.128	5.7	1.052	5.7	1.118	6.3	1.045	6.0
			45,000	H	—	1.357	4.99	H	—	1.257	5.0
	II	17.07 / .0495	30,000	.807	6.5	.747	6.5	.756	7.5	.757	6.9
			45,000	.978	5.5	.916	5.5	960	6.3	.926	5.8
			60,000	1.144	5.0	1.064	5.3	1.133	6.0	1.057	4.99
	III	19.20 / .0430	30,000	.571	7.6	.555	7.0	.550	8.1	.552	7.5
			45,000	.732	6.5	.679	6.0	.681	7.2	.690	6.4
			60,000	.848	5.7	.791	5.5	.801	6.5	.797	6.0
TRIPLE 1:2:1 C.S. (CENTER SCREW)	I	18.56 / .0455	15,000	.539	8.4	.521	7.4	.512	9.0	.517	8.0
			30,000	.801	6.0	.741	6.0	.751	7.4	.752	6.8
			45,000	.871	5.7	.910	5.4	.953	6.0	.921	5.9
	II	21.21 / .0397	30,000	.545	6.8	.522	6.5	.521	7.4	.524	6.8
			45,000	.692	6.0	.649	5.4	.655	6.3	.656	5.9
			60,000	.812	5.2	.752	5.0	.762	5.9	.761	5.0
	III	23.0 / .0367	30,000	L	—	L	—	L	—	L	—
			45,000	.546	6.0	.528	6.0	.521	7.5	.525	6.3
			60,000	.641	5.3	.613	5.2	.615	6.4	.615	5.5
TRIPLE 1:2:1 O.S. (OUTBOARD SCREW)	I	13.12 / .0643	15,000	.944	7.6	.884	7.4	.921	8.5	.896	7.9
			30,000	1.40	5.2	1.275	5.3	1.40	6.0	1.231	5.7
			45,000	H	—	H	—	H	—	H	—
	II	15.0 / .0562	30,000	.955	6.7	.894	6.1	.934	7.0	.906	7.0
			45,000	1.195	5.3	1.103	5.1	1.180	6.1	1.092	5.3
			60,000	H	—	1.291	4.9	H	—	1.244	4.9
	III	16.27 / .0519	30,000	.712	7.4	.664	7.5	.670	8.0	.673	7.5
			45000	.956	6.1	.895	5.8	.935	6.5	907	6.0
			60,000	1.007	5.9	.945	5.7	.994	6.3	.952	5.2
TRIPLE 1:2:1 (COMBINED C.S + 2(O.S))	I		15,000		8.3		7.4		8.75		8.0
			30,000		5.6		5.6		6.65		6.2
			45,000		—		—		—		—
	II		30,000		6.75		6.3		7.2		6.9
			45,000		5.6		5.25		6.2		5.6
			60,000		—		4.95		—		4.95
	III		30,000		..		—		—		—
			45,000		6.05		5.9		7.0		6.15
			60,000		5.6		5.45		6.35		5.65

TABLE 73

"Ehp Estimation"

Ayre:

$$Ehp = \frac{550}{760} \; \frac{D^{0.64}}{C} \; V^3_{m/sec}$$

$$= \frac{75}{76} \; \frac{D^{0.64}}{C} \; V^3_{knots}$$

$$= 0.985 \; \frac{D^{0.64} \, V^3}{C}$$

DETERMINATION OF C.

CASE $L \times B \times H$	D = Disp metric tons	$D^{0.64}$	$D^{1/3}$	$F = \frac{0.514 \times 18}{\sqrt{9.81 \times \ldots}}$	F	$\frac{LWL\,(\ldots)}{D^{1/3}}$	C
1 $300' \times 70' \times 25'$	8,600	420	20.5	$\frac{0.514 \times 18}{\sqrt{9.81 \times 300 \times 0.3\ldots}} = 0.31$	0.31	4.46	230
2 $350' \times 80' \times 3'$	12,200	530	23	$= \frac{9.26}{32.2} = 0.285$	0.288	4.6	280
3 $400' \times 30' \times 30'$	15,600	612	25	$= 9.25/34.5 = 0.268$	0.268	4.86	330

V^3_{knots}	$D^{0.64}$	C	Ehp
5,900	420	.230	10,600
5,900	530	280	11,000
5,900	612	330	10,800

TABLE 74 PITCH RATIOS FOR BOLLARD OPERATION. (AVERAGE DIAMETERS)

Max Total SHP		SCREW TYPE	TWIN SCREW			TRIPLE SCREW 1:1:1			TRIPLE SCREW 1:2:1					
									CENTER SCREW			OUT BOARD SCREW		
CASE I	CASE II		CASE I	CASE II	CASE III	CASE I	CASE II	CASE III	CASE I	CASE II	CASE III	CASE I	CASE II	CASE III
			D = 16.25'	D = 18.56'	D = 20.83'	D = 15.5'	D = 15.46'	D = 17.4'	D = 16.88	D = 19.2'	D = 21.62'	D = 11.81'	D = 13.6'	D = 15.29
15,000	30,000	B 3.50	.790	.801	.567	1.015	1.023	.767	.711	.731	.524	1.269	[illegible]	.912
		B 3.65	.730	.741	.551	.953	.961	.708	.663	.678	.501	1.163	1.155	.855
		B 4.55	.740	.751	.546	1.003	1.012	.718	.669	.687	L	1.253	1.243	[illegible]
		B 4.70	.741	.752	.543	.958	.965	.721	.672	[illegible]	[illegible]	1.142	1.136	[illegible]
30,000	45,000	B 3.50	1.115	.971	.726	H	1.300	.933	[illegible]	[illegible]	.650	H	H	1.127
		B 3.65	1.012	.910	.674	1.319	1.188	.874	[illegible]	.839	.622	H	H	1.051
		B 4.55	1.106	.952	.682	H	1.287	.907	.972	.860	.622	H	H	1.117
		B 4.70	1.036	.921	.689	1.312	1.163	.884	.950	.846	.622	H	1.363	1.049
45,000	60,000	B 3.50	H	1.135	.843	H	H	1.081	1.273	1.032	.713	H	H	1.344
		B 3.65	1.299	1.057	.785	H	1.378	1.014	1.166	.969	.713	H	H	1.225
		B 4.55	H	1.124	.795	H	H	1.074	1.258	1.020	.723	H	H	1.335
		B 4.70	1.247	1.050	.791	H	1.321	1.010	1.145	.972	.725	H	H	1.193
$\left(\frac{SHP}{SCREW}\right) / (SHP_{max})_{TOTAL}$			0.50			0.333			0.50			0.25		

TABLE 76 PITCH RATIOS FOR BOLLARD CONDITION (LIMIT DIAMETERS)

Max Shaft SHP		SCREW TYPE	TWIN SCREW			TRIPLE SCREW (1:1:1)			TRIPLE SCREW 1:2:1					
									CENTER SCREW			OUTBOARD SCREWS		
CASE I	CASE II-III		CASE I	CASE II	CASE III	CASE I	CASE II	CASE III	CASE I	CASE II	CASE III	CASE I	CASE II	CASE III
			D=18.90'	D=21.60'	D=23.0'	D=14.93'	D=17.0'	D=19.20'	D=18.56'	D=21.21'	D=23.0'	D=13.12'	D=15.0'	D=16.27'
15,000	30,000	B-3.50	.520	.525	L	.797	.807	.571	.539	.545	L	.944	.955	.712
		B-3.65	.495	.502	L	.737	.747	.555	.521	.528	L	.884	.894	.664
		B-4.55	L	.492	L	.747	.756	.550	.512	.521	L	.921	.934	.670
		B-4.70	.492	.499	L	.748	.757	.552	.517	.524	L	.896	.906	.673
30,000	45,000	B-3.50	.764	.652	.546	1.128	.978	.732	.801	.692	.546	1.40	1.195	.956
		B-3.65	.705	.621	.528	1.052	.916	.679	.741	.649	.528	1.275	1.163	.895
		B-4.55	.715	.624	.521	1.118	.960	.687	.751	.655	.521	1.40	1.180	.935
		B-4.70	.718	.624	.525	1.045	.926	.690	.752	.656	.525	1.231	1.092	.907
45,000	60,000	B-3.50	.929	.775	.641	H	1.144	.848	.971	.812	.641	H	H	1.007
		B-3.65	.871	.715	.613	1.307	1.064	.791	.910	.752	.613	H	1.291	.945
		B-4.55	.903	.725	.615	H	1.133	.801	.953	.762	.615	H	H	.994
		B-4.70	.881	.728	.615	1.257	1.057	.797	.921	.761	.615	H	1.244	.952
(SHP/screw)/(SHP fraction)			0.50			0.33			0.50			0.25		

TABLE 76 SAMPLE CALCULATION

PROPULSIVE EFFICIENCY AT SPEED OF 18 KNOTS

1. Calculation of the open water efficiency (η_o)

The procedure is similar to the one used for finding η_o at a speed of advance of one knot.

Using the same system, ie twin screw arrangement in case I and $SHP_{TOTAL} = 15000$ we have again $D = 16.25$ ft, $P/D = 0.790$

Let's find the efficiency at a free-running SHP of 12000

Now we have to take in account the wake fraction, as 18 knots is ship speed and not speed of advance.

The following values were used for wake fraction and thrust deduction

Screw	wake fraction (w)	Thrust deduction (t)
Center screw	0.25	0.15
Outboard Screw	0.10	0.10

We find $J = \dfrac{V_a}{nD} = \dfrac{V_s(1-w)}{nD}$, at $n = 140$ rpm:

$$J = \frac{18\,\text{knots} \cdot 1.689\,\frac{\text{ft/sec}}{\text{knot}} \cdot (1-0.1)}{(140/60) \cdot 16.25} = 0.722$$

$$K_Q = \frac{43.97 \cdot SHP}{n^3 D^5} = \frac{43.97 \cdot 12000}{(140/60)^3 \cdot 16.25^5} = 0.0180$$

TABLE 77 SAMPLE CALCULATION (cont'd)

For the above J and P/D, we get from Henschke's chart for a B-3.50 propeller that $K_Q = 0.0104$, which is not equal to the calculated K_Q at 140 rpm.

Let's try n = 160 rpm, for which we can find: $J = 0.631$, $K_Q = 0.0120$, and again from the chart, for the new J we find $K_Q = 0.0150$.

To summarize, we found.

n	K_Q (calculated)	K_Q (from chart)	J
140	0.0180	0.0104	0.722
160	0.0120	0.0150	0.631

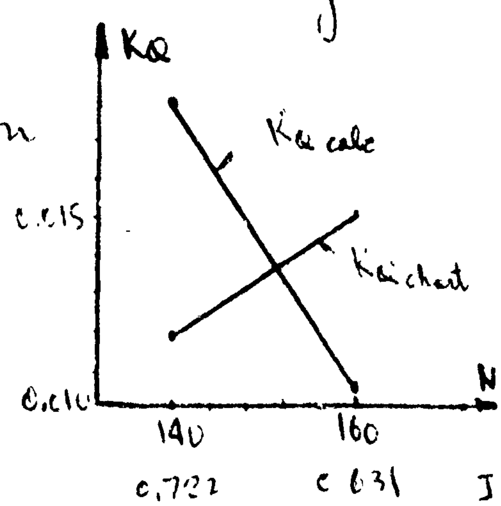
for $n = 140$ $K_{Q\,calc.} > K_{Q\,chart}$, while for $n = 160$ $K_{Q\,calc} < K_{Q\,chart}$

The equilibrium RPM is obviously between 140 and 160.

By graphical interpolation we can find

$N_{eq} = 156$ rpm

$J_{eq} = 0.652$



From J_{eq} and P/D we finally find $\eta_0 = 69.0\%$, from the chart.

TABLE 78 SAMPLE CALCULATION (CONT'D)

The propeller efficiency of all propellers is found similarly, and then the combined open water efficiency of the whole arrangement is found by:

$$\eta_{TOTAL} = \frac{1}{\sum \frac{SHP_i}{SHP_{total}} \cdot \frac{1}{\eta_{oi}}}$$

Results are summarized in tables 30 for average diameters and in tables for limit diameters

For the twin screw, as both propellers have equal efficiencies, the combined efficiency is equal to the efficiency of each propeller.

2. Calculation of Hull Efficiency

$$\eta_{Hi} = \frac{1-t_i}{1-w_i}$$

Using the values of t_i, w_i as assumed in table 77, we get

$$\eta_{Hc.s} = \frac{1-t_{cs}}{1-w_{cs}} = \frac{1-0.15}{1-0.25} = \frac{0.85}{0.75} = \frac{1}{0.9117}$$

$$\eta_{Ho.s} = 1, \text{ as } t_{o.s} = w_{o.s}$$

TABLE 79 SAMPLE CALCULATION (CONCLUDED)

Now we can calculate the total hull efficiency for the different arrangements, using:

$$\eta_{H\,total} = \frac{1}{\sum_i \frac{SHP_i}{SHP_{TOTAL}} \cdot \frac{1}{\eta_{Hi}}}$$ (i = each propeller in the arrangement.)

a) For twin screw

$$\eta_{H_{total}} = \eta_{Hi} = 1$$

b) For triple screw 1:1:1

$$\eta_{H_{total}} = \frac{1}{\underbrace{\frac{1}{3} \cdot 0.9117}_{C.S} + \underbrace{2 \cdot \frac{1}{3} \cdot 1}_{O.S.'s}} = 1.030$$

c) For triple-screw 1:2:1

$$\eta_{H_{total}} = \frac{1}{\frac{1}{2} \cdot 0.9117 + 2 \cdot \frac{1}{4} \cdot 1} = 1.046$$

3. Total propulsive efficiency (η_{P})

As $\eta_P = \eta_0 \cdot \eta_H \cdot \eta_R$, and assuming η_R, the rotative efficiency, to be unity for all cases - we get the total propulsive efficiency as:

$$\eta_{P_{total}} = \eta_{0\,total} * \eta_{H\,total},$$

using the calculated total open water efficiency ($\eta_{0\,total}$) and the total hull efficiency ($\eta_{H\,total}$)

TABLE 80 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE I TOTAL SHP = 30,000

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW 1:1:1						TRIPLE SCREW 1:2:1					
DIAMETER, FT.		18.90		14.93						18.56 × 13.12					
PROP TYPE	FREE RUNNING SHP	RPM	η_p [%]	C.S		O.S		η_o TOTAL [%]	η_p TOTAL [%]	CENTER SCREW		OUTBD. SCR.		η_o TOTAL [%]	η_p TOTAL [%]
				RPM	η_o [%]	RPM	η_o [%]			RPM	η_o [%]	RPM	η_o [%]		
B-3.65	6 000	125	45.0	L	–	L	–	–	–	L	–	L	–	–	–
	9 000	132	55.0	L	–	–	–	–	–	L	–	–	–	–	–
	12 000	137	55.6	123	68.4	131	72.0	70.9	73.0	127	61.0	128	74.0	67.0	70.1
	15 000	140	57.5	129	66.2	136	71.0	69.4	71.4	132	60.6	135	71.0	65.5	68.5
	18 000	145	60.0	135	64.2	141	69.0	67.4	69.4	137	60.0	139	69.2	64.4	67.4
B-4.70	6 000	122	40.0	L	–	L	–	–	–	L	–	L	–	–	–
	9 000	129	52.5	L	–	–	–	–	–	L	–	L	–	–	–
	12 000	135	56.2	121	68.6	130	70.6	70.0	72.1	124	61.0	124	70.0	65.2	68.2
	15 000	138	57.5	128	66.0	135	70.2	68.8	70.9	129	62.0	131	67.5	64.7	67.7
	18 000	143	59.6	132	65.0	139	68.5	67.3	69.3	134	61.4	136	65.8	63.5	66.4

L = TOO LOW F.R. SHP

TABLE 81 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE II TOTAL SHP = 45,000

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW 1:1:1						TRIPLE SCREW 1:2:1					
DIAMETER, FT		21.60		17.07						21.21 & 15.0					
PROP. TYPE	FREE RUNNING SHP	RPM	η_p [%]	C.S		O.S		η_o TOTAL [%]	η_p TOTAL [%]	C.S		O.S		η_o TOTAL [%]	η_p TOTAL [%]
				RPM	η_o [%]	RPM	η_o [%]			RPM	η_o [%]	RPM	η_o [%]		
B-3.65	12 000	126	45.2	L	–	–	–	–	–	L	–	L	–	–	–
	15 000	130	50.0	L	–	L	–	–	–	128	53.0	124	71.0	60.7	63.5
	18 000	134	50.2	123	65.2	131	69.0	67.8	69.8	132	54.0	129	72.0	61.7	64.5
	21 000	137	51.0	128	64.6	135	68.0	67.0	69.0	135	54.0	133	70.6	61.2	64.0
	24 000	140	52.6	132	63.4	138	67.0	65.7	67.7	137	55.4	136	70.0	61.9	64.7
B 4.70	12 000	123	40.0	L	–	–	–	–	–	L	–	L	–	–	–
	15 000	128	42.0	L	–	L	–	–	–	124	50.8	124	70.0	58.8	61.4
	18 000	132	50.0	120	66.2	129	67.5	67.1	69.1	129	52.0	128	70.4	59.8	62.5
	21 000	135	50.2	125	65.0	133	67.0	66.4	68.4	133	55.0	132	69.2	61.3	64.1
	24 000	138	53.0	129	64.0	136	67.0	66.0	68.0	138	55.4	135	68.4	61.2	64.0

L = TOO LOW F.R. SHP.

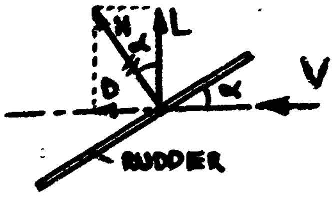
TABLE 82 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE III TOTAL SHP = 60,000

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW 1:1:1						TRIPLE SCREW 1:2:1					
DIAMETER, FT		23.00		19.20						23.0 - 16.26					
PROP. TYPE	FREE RUNNING SHP	RPM	η_P [%]	C. S. RPM	C. S. η_o [%]	O. S. RPM	O. S. η_o [%]	η_o TOTAL [%]	η_P TOTAL [%]	C. S. RPM	C. S. η_o [%]	O. S. RPM	O. S. η_o [%]	η_o TOTAL [%]	η_P TOTAL [%]
B-3.65	21 000	124	48.0	L	–	–	–	–	–	141	52.5	123	71.0	60.5	63.2
	24 000	128	52.0	122	62.4	131	64.0	63.5	65.4	143	53.3	127	70.2	60.6	63.4
	27 000	133	52.5	126	61.6	134	64.2	63.0	64.9	145	54.0	130	69.4	60.8	63.5
	30 000	136	52.5	129	60.6	137	63.2	62.3	64.1	147	53.2	133	68.0	59.7	62.4
B-4.70	21 000	128	50.0	L	–	–	–	–	–	128	46.0	122	70.6	55.7	58.2
	24 000	131	52.0	120	63.4	129	63.2	63.4	65.3	131	45.0	125	69.6	54.6	57.1
	27 000	131	52.0	124	62.6	132	64.2	63.5	65.4	133	50.0	128	68.5	57.9	60.5
	30 000	134	52.8	127	62.0	134	64.4	63.6	65.5	136	51.5	131	68.0	58.6	61.3

TABLE 83

Derivation of Rudder Force Expressions.



The rudder normal force N, and its componeents lift L, and drag D can be expressed in terms of nondimensional coefficients as functions of the inflow velocity V:

$$N = C_N \ \rho/2 \ V^2 A, \quad C_N = \text{normal force coefficient,}$$
$$L = C_L \ \rho/2 \ V^2 A, \quad C_L = \text{lift coefficient,}$$
$$D = C_D \ \rho/2 \ V^2 A, \quad C_D = \text{drag coefficient,}$$

where $C_N = C_L \cos\alpha + C_D \sin\alpha$

α = angle of incidence

A = rudder area

The coefficients depend on the rudder shape and on the angle of attack. The magnitude could be estimated by $C_N \approx 0.9$ both at $\alpha = 15$ deg. and $\alpha = 30$ deg., but there are major variations in them and thus some uncertainty as to the firgures for $\alpha = 30$ deg.

The inflow velocities into the rudder can be asserted as followed:

For the twin-screw design with central rudder:

$$V = V_S \ (1-w)$$

V_S = ship velocity

w = wake fraction, estimated as 0.04 at ship speed of 1 knot, and 0.225 at 18 knots.

For the triple-screw design with the same rudder arrangment:

$$V = V_S \ (1-w) + W_A$$

The velocity W_A is the fully developed axial induced velocity in the

TABLE 84

propeller race, and can be determined according to momentum theory:

$$W_A = V_A \left(-1 + \sqrt{1 + C_T}\right) =$$

$$= V_S\,(1-w)\,\left(-1 + \sqrt{1 + C_T}\right)\ .$$

where

C_T = thrust loading coefficient

$$C_T = \frac{T}{\frac{\rho}{2}\, V_s^2 \cdot (1-w)^2 \cdot A_D} = \frac{8}{\pi}\,\frac{K_T}{J^2}$$

$A_D = \frac{\pi}{4} D^2$ = disk area

V_A = propeller advance velocity

J = advance number

$K_T = T/(\rho N^2 D^4)$

The ratio of the rudder normal forces per unit rudder area for a triple-screw vessel to the corresponding forces for a twin-screw vessel is given by the following equations:

$$\frac{(N/A)_{TRIPLE}}{(N/A)_{TWIN}} = \frac{C_N \cdot \rho/2 \cdot V^2_{TRIPLE}}{C_N \cdot \rho/2 \cdot V^2_{TWIN}} = \frac{V^2_{TRIPLE}}{V^2_{TWIN}} =$$

$$\frac{V_s^2 \cdot (1-w)^2 \cdot \left[1 - 1 + \sqrt{1+C_T}\right]^2}{V_s^2\,(1-w)^2} = 1 + C_T$$

If this ratio is to be discussed as a function of SHP the evaluation procedure is as follows: For a given SHP, ship speed, wake fraction, and propeller diameter the equilibrium RPM must be determined first

TABLE 85

just like for the propeller efficiency in section X. This is done by means of propeller charts, such as Figures 5 and 6, estimating a few RPM and solving for the point where the advance number $J = V_A / N \cdot D$ corresponds to the one associated with the correct moment loading coefficient $k_m = SHP / (2\pi \rho D^5 N^3)$. When the RPM are known k_T can be read for the same advance number from the pertinent chart. This yields the desired quantity:

$$C_T = \frac{8}{\pi} \frac{K_T}{J^2}$$

The first part of the procedure is analogous to the sample of Table 76.

TABLE 86 RELATIVE RUDDER NORMAL FORCE

CASE: I TOTAL SHP= 30,000

PROPELLER TYPE: B 365

V = [illegible]

ARRANGEMENT	TRIPLE SCREW 1:1:1				TRIPLE SCREW 1:1:1			
DIA.(FT)	14.93				18.56			
SHP(FH)	9,000	12,000	15,000	18,000	9,000	12,000	15,000	18,000
P/D	1.052	1.052	1.052	1.052	.741	.741	.741	.741
Jec.	—	.769	.732	.700	—	.594	.575	.556
$(Jec.)^2$	—	.591	.536	.490	—	.353	.331	.309
K_T	—	.151	.170	.182	—	.090	.095	.107
$K_T/(Jec.)^2$	—	.255	.317	.371	—	.255	.287	.346
C_T	—	.649	.807	.944	—	.649	.730	.881
$1+C_T$	—	1.649	1.807	1.944	—	1.649	1.730	1.881

TABLE 27 RELATIVE RUDDER NORMAL FORCE

CASE: I TOTAL SHP= 30,000

PROPELLER TYPE: B.4.70

V - [illegible]

ARRANGEMENT	TRIPLE SCREW 1:1:1				TRIPLE SCREW 1: :1			
DIA. (FT)	14.93				18.56			
SHP (FP.)	9,000	12,000	15,000	18,000	9,000	12,000	15,000	18,000
P/D	1.045	1.045	1.045	1.045	.752	.752	.752	.752
Jeq.	—	.789	.739	.715	—	.612	.588	.566
$(Jeq)^2$	—	.610	.546	.511	—	.374	.346	.320
K_T	—	.162	.180	.195	—	.082	.098	.107
$K_T/(Jeq)^2$	—	.266	.330	.382	—	.219	.283	.334
C_T	—	.677	.840	.972	—	.557	.720	.850
$1+C_T$	—	1.677	1.840	1.972	—	1.557	1.720	1.850

TABLE [illegible] RELATIVE RUDDER NORMAL FORCE

CASE: II TOTAL SHP= 45,000

PROPELLER TYPE: B 3.65

ARRANGEMENT	TRIPLE SCREW 1:1:1				TRIPLE SCREW 1:2:1			
DIA. (FT)	17.07				21.21			
SHP (FR)	15,000	18,000	21,000	24,000	15,000	18,000	21,000	24,000
P/D	.916	.916	.916	.916	.649	.649	.649	.649
Jeq.	—	.673	.648	.628	.595	.577	.568	.556
$(Jeq.)^2$	—	.453	.420	.394	.354	.333	.323	.309
K_T	—	.132	.142	.150	.047	.055	.059	.062
$K_T/(Jeq.)^2$	—	.291	.338	.381	.133	.165	.183	.200
C_T	—	.741	.860	.970	.338	.420	.466	.509
$1+C_T$	—	1.741	1.860	1.970	1.338	1.420	1.466	1.509

TABLE 59 RELATIVE RUDDER NORMAL FORCE

CASE: II TOTAL SHP= 45,000

PROPELLER TYPE: B 4.70

ARRANGEMENT	TRIPLE SCREW 1:1:1				TRIPLE SCREW 1:2:1			
DIA. (FT)	17.07				21.21			
SHP (PR)	15,000	18,000	21,000	24,000	15,000	18,000	21,000	24,000
P/D	.926	.926	.926	.926	.656	.656	.656	.656
Jeq.	—	.690	.664	.642	.614	.590	.572	.552
$(Jeq.)^2$	—	.476	.441	.412	.377	.348	.317	.305
K_T	—	.140	.156	.164	.040	.052	.063	.070
$K_T/(Jeq.)^2$	—	.294	.354	.398	.106	.149	.199	.229
C_T	—	.748	.901	1.013	.270	.379	.506	.583
$1+C_T$	—	1.748	1.901	2.013	1.270	1.379	1.506	1.583

TABLE 90 RELATIVE RUDDER NORMAL FORCE

CASE: III TOTAL SHP= 60,000

PROPELLER TYPE: B 365

ARRANGEMENT	TRIPLE SCREW 1:1:1				TRIPLE SCREW 1:2:1			
DIA. (FT)	19.20				23.00			
S P (FR)	21,000	24.000	27.000	30.000	21.000	24.000	27.000	30.000
P/D	.791	.791	.791	.791	.613	.613	.613	.613
Jen.	—	.604	.586	.571	.540	.532	.525	.519
$(Jen.)^2$	—	.365	.343	.326	.292	.283	.276	.269
K_T	—	.104	.110	.117	.054	.059	.061	.063
$K_T/(Jen.)^2$	—	.285	.321	.359	.185	.208	.221	.234
C_T	—	.725	.817	.914	.471	.529	.562	.595
$1+C_T$	—	1.725	1.817	1.914	1.471	1.529	1.562	1.595

TABLE 91 RELATIVE RUDDER NORMAL FORCE

CASE: II TOTAL S.HP= 60,000

PROPELLER TYPE: B 4.70

ARRANGEMENT	TRIPLE SCREW 1:1:1				TRIPLE SCREW 1:[illegible]:1			
DIA.(FT)	19.20				23.00			
SHP(FR)	21,000	24,000	27,000	30,000	21,000	24,000	27,000	30,000
P/D	.797	.797	.797	.797	.615	.615	.615	.615
Jeq.	—	.614	.594	.580	.595	.581	.572	.560
$(Jeq.)^2$	—	.377	.353	.336	.354	.336	.327	.314
K_T	—	.110	.119	.124	.034	.037	.043	.049
$K_T/(Jeq.)^2$	—	.292	.337	.369	.096	.110	.131	.156
C_T	—	.743	.858	.939	.244	.280	.333	.397
$1+C_T$	—	1.743	1.858	1.939	1.244	1.280	1.333	1.397

TABLE: 92

RELATIVE RUDDER FORCE AT SPEED OF ADVANCE OF 1 KNOT

CENTERLINE SCREWS

PROPELLER TYPE: B3.65 CASE: I

ARRANGEMENT	TRIPLE 1:1:1			TRIPLE 1:2:1		
DIA. (FT)	14.93			18.56		
J	.0565			.0455		
SHP TOTAL	15,000	30,000	45,000	15,000	30,000	45,000
P/D	.737	1.052	1.307	.521	.741	.910
K_T	0.290	0.398	0.564	0.186	0.294	0.375
J^2	.0032	.0032	.0032	.0021	.0021	.0021
K_T/J^2	90.625	124.37	176.25	141.71	222.47	285.700
C_T	230.82	316.77	448.91	360.93	566.63	727.67
$1 + C_T$	231.82	317.77	449.91	361.93	567.63	728.67

TABLE: 93

RELATIVE RUDDER FORCE AT SPEED OF ADVANCE OF 1 KNOT

CENTERLINE SCREWS

PROPELLER TYPE: B 4.70 CASE: I

ARRANGEMENT	TRIPLE 1:1:1			TRIPLE 1:2:1		
DIA. (FT)	14.93			18.56		
J	.0565			.0455		
SHP TOTAL	15,000	30,000	45,000	15,000	30,000	45,000
P/D	.748	1.045	1.257	.517	.752	.921
K_T	0.308	0.462	*	0.196	0.314	0.404
J^2	.0032	.0032	.0032	.0021	.0021	.0021
K_T/J^2	96.25	144.37	—	149.33	239.200	307.300
C_T	245.15	367.71	—	380.34	609.24	783.96
$1 + C_T$	246.15	368.71	—	381.34	610.24	784.96

* OUT OF PROPELLER CHART

TABLE: 94

RELATIVE RUDDER FORCE AT SPEED OF ADVANCE OF 1 KNOT

CENTERLINE SCREWS

PROPELLER TYPE: B 3.65 CASE: II

ARRANGEMENT	TRIPLE 1:1:1			TRIPLE 1:2:1		
DIA. (FT)	17.07			21.21		
J	.0495			.0397		
SHP TOTAL	30,000	45,000	60,000	30,000	45,000	60,000
P/D	.747	.916	1.064	.528	.649	.752
K_T	0.295	0.378	0.454	0.195	0.250	0.300
J^2	.0025	.0025	.0025	.0016	.0016	.0016
K_T/J^2	118.00	151.20	181.6	121.87	156.25	187.50
C_T	300.54	385.10	462.53	310.40	397.96	477.5
$1 + C_T$	301.54	386.10	463.53	311.40	398.96	478.5

TABLE: 95

RELATIVE RUDDER FORCE AT SPEED OF ADVANCE OF 1 KNOT

CENTERLINE SCREWS

PROPELLER TYPE: B 470 CASE: II

ARRANGEMENT	TRIPLE 1:1:1			TRIPLE 1:2:1		
DIA. (FT)	17.07			21.21		
J	.0495			.0397		
SHP TOTAL	30,000	45,000	60,000	30,000	45,000	60,000
P/D	.757	.926	1.057	.524	.656	.761
K_T	0.318	0.410	0.472	0.202	0.268	0.320
J^2	.0025	.0025	.0025	.0016	.0016	.0016
K_T/J^2	127.20	164.0	188.8	126.25	167.50	200.00
C_T	323.98	417.70	480.87	321.56	426.62	509.40
$1 + C_T$	324.98	418.70	481.87	322.56	427.62	510.40

TABLE: 96

RELATIVE RUDDER FORCE AT SPEED OF ADVANCE OF 1 KNOT

CENTERLINE SCREWS

PROPELLER TYPE: B 3.65

CASE: III

ARRANGEMENT	TRIPLE 1:1:1			TRIPLE 1:2:1		
DIA. (FT)	19.20			23.00		
J	.0430			.0367		
SHP TOTAL	30,000	45,000	60,000	30,000	45,000	60,000
P/D	.555	.679	.791	L	.528	.613
K_T	0.204	0.264	0.316	–	0.195	0.235
J^2	.0018	.0018	.0018	–	.0013	.0013
K_T/J^2	113.22	146.52	175.38	–	149.99	180.76
C_T	288.37	373.19	446.69	–	382.02	460.39
$1 + C_T$	289.37	374.19	447.69	–	383.02	461.39

TABLE: 37

RELATIVE RUDDER FORCE AT SPEED OF ADVANCE OF 1 KNOT

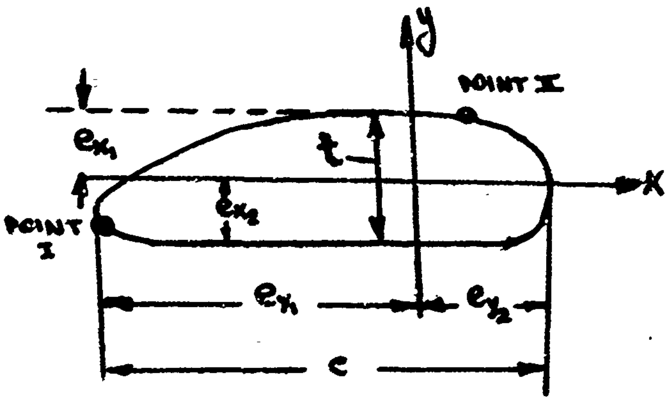
CENTERLINE SCREWS

PROPELLER TYPE: B 470 CASE: III

ARRANGEMENT	TRIPLE 1:1:1			TRIPLE 1:2:1		
DIA. (FT)	19.20			23.00		
J	.0430			.0367		
SHP TOTAL	30,000	45,000	60,000	30,000	45,000	60,000
P/D	.552	.690	.797	∠	.525	.615
K_T	0.212	0.280	0.335	–	0.205	0.245
J^2	.0018	.0018	.0018	–	.0013	.0013
K_T/J^2	117.66	155.40	185.92	–	157.68	188.45
C_T	299.68	395.80	473.54	–	401.61	479.98
$1 + C_T$	300.68	396.80	473.54	–	402.61	480.98

TABLE 98

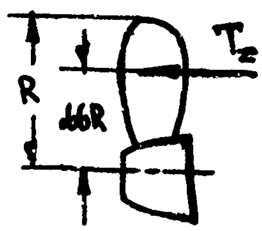
<u>Derivation of Propulsive Stresses for Troost Series Propellers.</u>



The critical stresses to be analyzed occur in the root profile assumed at 0.2R, see sketch. The influence of centrifugal forces is neglected, i.e. the rake is assumed to be zero. The load is then consisting of thrust and torque.

The <u>thrust</u> results in axial bending moments at the blades:

$$M_A = 0.46 \cdot R \cdot T_z \text{ for 0.2R profile,}$$



where:

$T_z = \frac{T}{z}$ = thrust per blade

R = propeller radius

0.46 R = estimated distance from root profile at 0.2R to location of thrust resultant on blade, estimated as 0.66R.

The torque produces a circumferential bending moment:

$$M_C = d. \frac{Q}{z}$$

where:

Q/z = torque per balde

$d \approx 0.6$ = distance from root profile at 0.2R to location of resulting circumferential force at about 0.8R, nondimensionalized by R.

TABLE 99

The x-y compoenents of these moments are:

$$M_X = M_A \cdot \sin\alpha - M_C \cdot \cos\alpha$$

$$M_y = M_A \cdot \cos\alpha + M_C \cdot \sin\alpha$$

where α = pitch angle at 0.2R, given by:

$$\tan\alpha = \frac{P}{D} \cdot \frac{1}{0.2\pi}$$

The stresses are then at the trailing edge, point I:

$$\sigma_I = \frac{M_x}{S_{y_1}} + \frac{M_y}{S_{x_2}}$$

with

$$S'_{y_1} = \frac{I_y}{e_{y_1}} = c^2 \cdot t \cdot \frac{\beta_y}{\varepsilon_{y_1}} \quad \text{= section modulus}$$

$$S'_{x_2} = \frac{I_x}{e_{x_2}} = c^2 t \frac{\beta_x}{\varepsilon_{x_2}} \quad \text{= section modulus}$$

I_x, I_y = moments of inertia

e_{x_2}, e_{y_1} = distance of trailing edge from centroid

c = chord length

t = thickness of foil

$$\beta_x, \beta_y = \frac{I_x}{c t^3}, \dots \quad \text{= nondim. foil shape parameter}$$

$$\varepsilon_{x_2}, \varepsilon_{y_1} = \frac{e_{x_2}}{t}, \dots \quad \text{= nondim. foil shape parameter}$$

According to reference 11, page 94, the following numerical values hold for root profiles of Troost propellers:

$$\varepsilon_{x_2} = 0.464$$

TABLE 100

$$\varepsilon_{y_1} = 0.555$$
$$\beta_x = 0.455$$
$$\beta_y = 0.039$$

Chord length c, and foil thickness t must be determined for the various types of Troost propellers. According to reference 11, pages 14 through 16, it follows from the geometry of the series that:

$$C = C_{0.2R} = \frac{C_{0.2R}}{C_{0.6R}} \cdot \frac{C_{0.6R}}{D} \cdot D = f_c \cdot D$$

$$t = f_t \cdot D$$

with $\quad f_c = \frac{C_{0.2R}}{C_{0.6R}} \cdot \frac{C_{0.6R}}{D}$

The numerical values are tabulated below.

Series	$\frac{C0.2}{C0.6}$	$\frac{C0.6}{D}$	f_c	f_t
B3.35	0.7473	0.2589	0.194	0.0406
B3.50	0.7473	0.3698	0.277	0.0406
B3.65	0.7473	0.4810	0.360	0.0406
B4.40	.07608	0.2187	0.164	0.0366
B4.55	0.7608	0.3829	0.286	0.0366
B4.70	0.7608	0.5007	0.374	0.0366

TABLE: 101

STRESS AT THE BOLLARD CONDITION

CASE: I

ARR.	TOTAL SHP	15,000		30,000		45,000	
	PROP. TYPE	B 3.65	B 4.70	B 3.65	B 4.70	B 3.65	B 4.70
TWIN SCREW $D = 18.9'$	THRUST $\times 10^5$ lbs	(–)	(–)	2.922	3.133	3.764	3.964
	TORQUE $\times 10^5$ lb-ft	(–)	(–)	6.564	6.564	9.846	9.846
	STRESS, psi	(–)	(–)	1304.94	1169.33	1752.99	1529.9
TRIPLE SCREW 1:1:1 $D = 14.93'$	THRUST $\times 10^5$, lbs	1.198	1.278	1.831	1.883	2.266	2.367
	TORQUE $\times 10^5$ lb-ft	2.188	2.188	4.376	4.376	6.564	6.564
	STRESS, psi	865.55	769.95	1414.4	1197.88	1822.22	1556.09
	STRESS/STRESS$_{twin}$	*	*	1.084	1.024	1.039	1.017
TRIPLE SCREW 1:2:1 & $D = 18.56'$	THRUST $\times 10^5$, lbs	1.856	1.946	2.881	3.072	3.697	3.883
	TORQUE $\times 10^5$ lb-ft	3.282	3.282	6.564	6.564	9.846	9.846
	STRESS, psi	802.57	705.84	1348.4	1197.99	1799.74	1564.90
	STRESS/STRESS$_{twin}$	*	*	1.033	1.024	1.026	1.023
TRIPLE SCREW 1:2:1 OUTBOARD $D = 13.12'$	THRUST $\times 10^5$ lbs	.891	.939	1.321	1.376	(–)	(–)
	TORQUE $\times 10^5$ lb-ft	1.641	1.641	3.280	3.280	(–)	(–)
	STRESS, psi	863.76	753.83	1368.24	1166.30	(–)	(–)
	STRESS/STRESS$_{twin}$	*	*	1.048	.997	(–)	(–)

(–) P/D OUT OF RANGE

* MEANINGLESS VALUE DUE TO (–)

TABLE: 102

STRESS AT THE BOLLARD CONDITION

CASE: II

ARR.	TOTAL SHP	30,000		45,000		60,000	
	PROP. TYPE	B 3.65	B 4.70	B 3.65	B 4.70	B 3.65	B 4.70
TWIN SCREW D = 21.6	THRUST × 10^5 lbs	3.227	(-)	4.287	4.451	5.066	5.426
	TORQUE × 10^5 ft lbs	6.564	(-)	9.846	9.846	13.128	13.128
	STRESS, psi	1019.84	(-)	1428.32	1238.77	1731.48	1553.99
TRIPLE SCREW 1:1:1 D = 17.07	THRUST × 10^5 lbs	2.079	2.214	2.798	2.798	3.166	3.258
	TORQUE × 10^5 ft lbs	4.376	4.376	6.564	6.564	8.752	8.752
	STRESS, psi	1151.99	1021.93	1537.4	1334.51	1874.80	1588.36
	STRESS/STRESS twin	1.129	*	1.076	1.077	1.079	1.022
TRIPLE SCREW 1:2:1 € D = 21.21	THRUST × 10^5 lbs	3.229	3.365	4.202	4.423	4.998	5.316
	TORQUE × 10^5 ft lbs	6.564	6.564	9.846	9.846	1.313	13.128
	STRESS, psi	1073.58	937.11	1465.29	1289.29	1796.23	1590.89
	STRESS/STRESS twin	1.0526	*	1.025	1.041	1.034	1.023
TRIPLE SCREW 1:2:1 OUTBOARD D = 15.0	THRUST × 10^5 lbs	1.504	1.625	1.956	2.018	2.282	2.382
	TORQUE × 10^5 ft lbs	3.282	3.282	4.923	4.923	6.564	6.564
	STRESS, psi	1147.09	1000.52	1510.15	1281.44	1814.15	1547.68
	STRESS/STRESS twin	1.125	*	1.057	1.034	1.044	.996

(-) P/D OUT OF RANGE

* MEANINGLESS VALUE DUE TO (-)

TABLE: 103

STRESS AT THE BOLLARD CONDITION . CASE: III

ARR.	TOTAL SHP	30,000		45,000		60,000	
	PROP. TYPE	B 3.65	B 4.70	B 3.65	B 4.70	B 3.65	B 4.70
TWIN SCREW D= 23.0	THRUST $\times 10^5$ lb	(-)	(-)	4.467	4.654	5.426	5.614
	TORQUE $\times 10^5$ #-ft	(-)	(-)	9.846	9.846	13.128	13.128
	STRESS psi	(-)	(-)	1262.85	1102.22	1589.82	1373.88
TRIPLE SCREW 1:1:1 D= 19.2	THRUST $\times 10^5$ lbs	2.321	2.385	2.973	3.172	3.566	3.758
	TORQUE $\times 10^5$ #-ft	4.376	4.376	6.564	6.564	8.753	8.752
	STRESS , psi	1453.37	818.98	1276.43	1139.25	1580.22	1382
	STRESS/STRESS$_{twin}$	*	*	1.0107	1.0336	.993	1.006
TRIPLE SCREW 1:2:1 ℄ D= 23.0	THRUST $\times 10^5$ lbs	(-)	(-)	4.467	4.654	5.426	5.614
	TORQUE $\times 10^5$ #-ft	(-)	(-)	9.846	9.846	13.128	13.128
	STRESS , psi	(-)	(-)	1262.85	1102.22	1589.8	1373.88
	STRESS/STRESS$_{twin}$	*	*	1.000	1.000	1.000	1.000
TRIPLE SCREW 1:2:1 OUTBOARD D= 16.26	THRUST $\times 10^5$ lb	1.662	1.777	2.134	2.2472	2.548	2.620
	TORQUE $\times 10^5$ #-ft	3.282	3.282	4.923	4923	6.564	6.564
	STRESS , psi	1010.09	900.59	1349.86	1171.30	1656.43	1402.66
	STRESS/STRESS$_{twin}$	*	*	1.069	1.068	1.042	1.021

(-) P/D OUT OF RANGE

* MEANINGLESS VALUE DUE TO (-)

TABLE 104

<u>Determination of Propeller--Induced Vibratory Forces Acting on Hull in Way of Propeller</u>.

According to reference 14, the pressures induced by a propeller blade in its top position at a field point in its vicinity, which has the axial, radial, and angular coordinates x, r, γ, are given by two contributions:

The pressure due to blade <u>loading</u>:

$$P_L = \frac{T}{A_o}\left(-\frac{x}{r}\cdot\sqrt{\frac{b}{r}}\cdot J(z)\cdot\cos m\gamma + \sqrt{\frac{b}{r}}\cdot J\cdot Q(z)\sin m\gamma\right)$$

The pressure due to blade <u>thickness</u>:

$$P_T = \rho U b N\frac{t}{c}\cos(m\sigma_o+\epsilon)\cdot\left[-\sqrt{\frac{b}{r}}\cdot\Theta(z)\cdot\cos m\gamma + \frac{x}{r}\sqrt{\frac{b}{r}}\cdot\frac{\Phi(z)}{J}\sin m\gamma\right]$$

The out-of-phase components of these pressures are omitted because they are not needed to find the maximum pressure.

The notation is as follows:

ρ = fluid density

U = forward velocity

t/C = mean thickness ratio of blade sections

σ_o = half the sector angle formed by the projection of the blade on the plane of rotation

$\epsilon = \tan^{-1}(1/m\sigma_o)$

m = no. of blades

$J = \frac{U}{2bN}$ = advance number

b = propeller radius

TABLE 105

T = thrust

A_D = propeller disk area

The functions $J(z)$, $Q(z)$, $\Theta(z)$, $\Phi(z)$ are tabulated in reference 14; they depend on the distance between field point and propeller blade. The pressure equations for zero advance speed (bollard condition) can be simplified:

$$P_L = \frac{T}{A_D}\left(-\frac{x}{r}\sqrt{\frac{b}{r}}\; J(z)\cdot\cos m\gamma\right)$$

$$P_T = \rho b^2 N^2 \frac{t}{c}\cos(m\sigma_0+\varepsilon)\cdot\frac{x}{r}\sqrt{\frac{b}{r}}\;\Phi(z)\sin m\gamma$$

The total pressure is obtained by superposition:

$$P = -\left[\frac{T}{A_D}\cdot\frac{x}{r}\sqrt{\frac{b}{r}}\cdot J(z) + \rho U b N \frac{t}{c}\cos(m\sigma_0+\varepsilon)\sqrt{\frac{b}{r}}\,\Theta(z)\right]\cos m\gamma$$

$$-\left[\sqrt{\frac{b}{r}}\cdot J\cdot Q(z) + \rho U b N\frac{t}{c}\cos(m\sigma_0+\varepsilon)\frac{x}{r}\sqrt{\frac{b}{r}}\,\frac{\Phi(z)}{J}\right]\sin m\gamma$$

$$= a_1\cos m\gamma + a_2\sin m\gamma$$

The maximum amplitude of this blade-frequency pressure becomes:

$$P = \sqrt{a_1^2 + a_2^2}$$

where a_1, a_2 as defined above.

In the bollard condition the special solution is

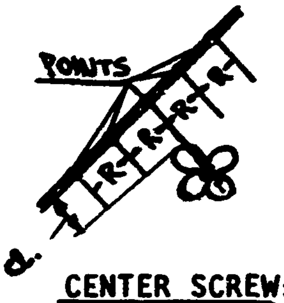
$$a_1 = -\frac{T}{A_D}\,\frac{x}{r}\sqrt{\frac{b}{r}}\;J(z)$$

$$a_2 = \rho b^2 N^2\cdot\frac{t}{c}\cdot\cos(m\sigma_0+\varepsilon)\cdot\frac{x}{r}\sqrt{\frac{b}{r}}\;\Phi(z)$$

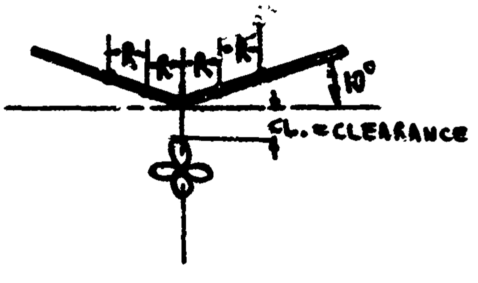
TABLE 106

In integrating the pressures to obtain the forces on the hull the following schemes were used:

OUTER SCREW:



CENTER SCREW:



The pressures were determined at five points in the propeller plane as shown, and also in the two planes one radius R before and abaft the propeller plane.

Each pressure was multiplied by the area of the rectangular elements surrounding the points, bounded by lines halfway towards the neighboring point.

TABLE 107 RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS

CASE I   TOTAL SHP 30000   PROPELLER TYPE B 3.65

ARRANGEMENT AND DIAMETER, FT		FREE RUNNING SHP 10^3	N RPM	THRUST 10^4 LBS.	FORCE, 10^4 LBS CLEARANCE / DIA. 0.1	0.3	0.6	FORCE / THRUST CLEARANCE / DIA. 0.1	0.3	0.6
TWIN SCREW	D = 18.90'	9	132	4.918	.7281	.3548	.1526	.148	.072	.0310
		12	137	7.283	.7855	.3803	.1628	.108	.052	.022
		15	1..0	8.297	.8227	.3977	.1683	.099	.048	.020
		18	145	10.38	.9138	.4452	.1816	.088	.042	.017
TRIPLE SCREW 1:1:1	CENTER SCREW D = 18.93	9	—	—	—	—	—	—	—	—
		12	123	6.276	.8763	.2131	0.073	.1396	.033	.011
		15	.129	7.772	1.016	.2502	0.084	.1306	.032	.010
		18	135	9.112	1.136	.2824	0.095	.1246	.030	.010
	OUTBD. SCREW D =	9	–	–	–	–	–	–	–	–
		12	131	6.223	.5423	.2640	.1075	.0871	.042	.017
		15	136	7.012	.5869	.2867	.1158	.083	.040	.016
		18	141	8.193	.6526	.3203	.1282	.079	.0391	.016
TRIPLE SCREW 1:2:1	CENTER SCREW D = 10.56	9	—	—	—	—	—	—	—	—
		12	127	9.524	1.327	.313	.1096	.1393	.032	.011
		15	132	10.86	1443	.344	.1174	.1328	.031	.010
		18	137	13.17	1.628	.396	.1307	.1235	.0300	.009
	OUTBD SCREW D =	9	–	–	–	–	–	–	–	–
		12	128	4.428	.4107	.1996	.0819	.092	.045	.018
		15	135	5.524	.4799	.2345	.0952	.086	.042	.017
		18	139	6.457	.5397	.2647	.1068	.083	.041	.0165

TABLE 108 RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS

CASE II TOTAL SHP 45000 PROPELLER TYPE B 3.65

ARRANGEMENT AND DIAMETER, FT		FREE RUNNING SHP 10^3 x	N RPM	THRUST 10^4 LBS.	FORCE, 10^4 LBS CLEARANCE/DIA. 0.1	0.3	0.6	FORCE/THRUST CLEARANCE/DIA. 0.1	0.3	0.6
TWIN SCREW	D = 21.80	15	130	7.322	1.073[illegible]	.5258	.224[illegible]	.146	.071	.030
		18	134	9.509	1.131	.5533	.2347	.119	.058	.024
		21	137	11.29	1.184	.5784	.2428	.104	.051	.021
		24	140	12.97	1.242	.6075	.2506	.096	.046	.019
TRIPLE SCREW 1:1:1	CENTER SCREW D = 17.07	15	—	—	—	—	—	—	—	—
		18	123	9.375	1.233	.300	.1019	.1315	.032	.010
		21	128	10.92	1.368	.3365	.1125	.1252	.0308	.010
		24	132	[illegible]	1.481	.3673	.1215	.1207	.0299	.009
	OUTBD. SCREW D =	15	—	—	—	—	—	—	—	—
		18	131	8.217	.7130	.3453	.1407	.086	.042	.017
		21	135	9.668	.7884	.3851	.1547	.082	.039	.016
		24	138	10.73	.844	.4137	.1648	.079	.038	.015
TRIPLE SCREW 1:2:1	CENTER SCREW D = 21.21	15	128	8.616	1.833	.419	.1702	.2127	.048	.019
		18	132	10.72	1.964	.444	.1786	.1831	.0414	.016
		21	135	12.03	2.070	.466	.1856	.1720	.038	.015
		24	137	13.02	2.131	.483	.1887	.1631	.037	.014
	OUTBD SCREW D =	15	124	5.595	.5089	.2470	.1014	.091	.044	.018
		18	129	6.893	.5859	.2861	.1159	.085	.041	.016
		21	133	7.625	.6280	.3075	.1238	.082	.040	.016
		24	136	8.387	.6729	.3304	.1324	.080	.039	.015

TABLE 109 RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS

CASE III TOTAL SHP 60,000 PROPELLER TYPE B. 3.65

ARRANGEMENT AND DIAMETER, FT		FREE RUNNING SHP 10^3 x	N RPM	THRUST 10^4 LBS.	FORCE, 10^4 LBS CLEARANCE / DIA. 0.1	0.3	0.6	FORCE / THRUST CLEARANCE / DIA. 0.1	0.3	0.6
TWIN SCREW	D = 23.00	21	124	9.516	1.248	.6111	.2603	.131	.064	.027
		24	128	11.11	1.306	.6391	.2705	.117	.057	.024
		27	133	14.78	1.421	.6956	.2869	.096	.047	.019
		30	136	17.17	1.510	.7425	.2989	.087	.043	.017
TRIPLE SCREW 1:1:1	CENTER SCREW D = 19.20	21	—	—	—	—	—	—	—	—
		24	129	11.63	1.541	.3696	.1257	.1324	.031	.010
		27	126	13.12	1.664	.4034	.1348	.1268	.030	.010
		30	129	14.63	1.782	.436	.1437	.1218	.029	.009
	OUTBD. SCREW D = 19.20	21	—	—	—	—	—	—	—	—
		24	131	10.31	.900	.4375	.1788	.087	.042	.017
		27	134	11.47	.9578	.4673	.1882	.083	.040	.016
		30	137	12.97	1.031	.5051	.2006	.079	.038	.015
TRIPLE SCREW 1:2:1	CENTER SCREW D = 23.00	21	141	16.61	2.931	.665	.2651	.176	.040	.016
		24	143	18.66	3.058	.694	.2716	.164	.037	.0145
		27	145	19.84	3.147	.7185	.2771	.158	.036	.014
		30	147	21.06	3.243	.744	.2830	.154	.035	.0134
TRIPLE SCREW	OUTBD SCREW D = 16.26	21	123	7.370	.6392	.3111	.1267	.087	.042	.017
		24	127	8.728	.7182	.3513	.1414	.082	.040	.016
		27	130	9.797	.7776	.3817	.1526	.079	.038	.015
		30	133	10.53	.8180	.4024	.1603	.077	.038	.015

TABLE 110 RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS

CASE I   TOTAL SHP 30,000   PROPELLER TYPE B470

ARRANGEMENT AND DIAMETER, FT		FREE RUNNING SHP 10^3	N RPM	THRUST 10^4 LBS.	FORCE, 10^4 LBS CLEARANCE/DIA. 0.1	0.3	0.6	FORCE/THRUST CLEARANCE/DIA. 0.1	0.3	0.6
TWIN SCREW	D = 18.90	9	129	5.400	.3498	.1317	.0455	.064	.024	.008
		12	135	7.714	.3762	.1424	.0492	.049	.018	.006
		15	138	8.733	.3906	.1492	.0512	.044	.017	.005
		18	143	1.154	.4266	.1677	.0555	.037	.014	.004
TRIPLE SCREW 1:1:1	CENTER SCREW D = 14.93	9	—	—	—	—	—	—	—	—
		12	121	6.516	.5912	.069	.0198	.0907	.010	.003
		15	128	8.102	.6775	.079	.0222	.0836	.009	.0027
		18	132	9.334	.7419	.087	.0239	.0795	.009	.0025
	OUTBD. SCREW D = 14.93	9	—	—	—	—	—	—	—	—
		12	130	6.036	.2328	.0913	.0300	.038	.015	.004
		15	135	6.959	.2511	.0996	.021	.036	.014	.004
		18	139	8.174	.2761	.1009	.0352	.034	.013	.004
TRIPLE SCREW 1:2:1	CENTER SCREW D = 18.56	9	—	—	—	—	—	—	—	—
		12	124	8.272	.8536	.097	.0306	.103	.011	.0037
		15	129	10.69	.9585	.109	.0333	.089	.010	.0031
		18	134	12.60	1.043	.119	.0355	.0827	.009	.0028
TRIPLE SCREW	OUTBD SCREW D =	9	—	—	—	—	—	—	—	—
		12	124	5.793	.2170	.0863	.0279	.0374	.015	.005
		15	131	7.253	.2530	.1018	.0324	.034	.014	.004
		18	136	8.151	.2735	.1107	.0350	.033	.013	.004

TABLE III RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS

CASE II TOTAL SHP 45,000 PROPELLER TYPE B 4.70

ARRANGEMENT AND DIAMETER, FT		FREE RUNNING SHP 10^3	N RPM	THRUST 10^4 LBS.	FORCE, 10^4 LBS CLEARANCE/DIA. 0.1	0.3	0.6	FORCE/THRUST CLEARANCE/DIA. 0.1	0.3	0.6
TWIN SCREW D = 21.60'		15	128	5.915	.5067	.1923	.0653	.086	.032	.011
		18	132	9.017	.5323	.2027	.0690	.059	.022	.007
		21	135	10.96	.5517	.2110	.0717	.050	.019	.006
		24	138	11.91	.5678	.2180	.0739	.047	.018	.006
TRIPLE SCREW 1:1:1	CENTER SCREW D = 17.07	15	—	—	—	—	—	—	—	—
		18	120	9.464	.8163	.094	.0275	.086	.010	.0029
		21	125	11.44	.9169	.1064	.0301	.080	.009	.0026
		24	129	1.281	.9811	.1139	.0318	.076	.008	.0024
	OUTBD. SCREW D =	15	—	—	—	—	—	—	—	—
		18	129	8.980	.3284	.1296	.0422	.036	.014	.005
		21	133	10.63	.3596	.1440	.0458	.034	.013	.004
		24	136	11.37	.3740	.1505	.0475	.033	.013	.004
TRIPLE SCREW 1:2:1	CENTER SCREW D = 21.21	15	124	6.8821	1.269	.1468	.0477	.184	.021	.0069
		18	129	9.682	1.362	.1567	.0507	.1407	.016	.0052
		21	133	12.469	1.459	.166	.0535	.117	.013	.0043
		24	138	14.916	1.567	.176	.0565	.105	.011	.0038
	OUTBD SCREW D =	15	124	5.681	.2254	.0881	.0291	.03968	.015	.005
		18	128	6.787	.2494	.0988	.0320	.0367	.014	.004
		21	132	7.657	.2673	.1068	.0341	.035	.014	.004
		24	135	8.468	.2849	.1146	.0363	.033	.013	.004

TABLE 112 RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS.

CASE III TOTAL SHP 60,000 PROPELLER TYPE 84.70

ARRANGEMENT AND DIAMETER, FT		FREE RUNNING SHP 10^3x	N RPM	THRUST 10^4 LBS.	FORCE, 10^4 LBS CLEARANCE / DIA. 0.1	0.3	0.6	FORCE / THRUST CLEARANCE / DIA. 0.1	0.3	0.6
TWIN SCREW	D = 23.00	21	128	12.16	.6286	.2405	.0817	.052	.019	.006
		24	131	13.80	.6509	.2503	.0847	.047	.018	.006
		27	131	13.80	.6509	.2503	.0847	.047	.018	.006
		30	134	16.39	.6757	.2630	.0881	.041	.016	.005
TRIPLE SCREW 1:1:1	CENTER SCREW D = 19.20'	21	—	—	—	—	—	—	—	—
		24	120	11.90	1.039	.119	.0357	.087	.010	.003
		27	124	13.74	1.123	.128	.0379	.081	.009	.0027
		30	127	15.02	1.181	.135	.0394	.078	.009	.0026
	OUTBD. SCREW D = 19.20'	21	—	—	—	—	—	—	—	—
		24	129	10.75	.4021	.1609	.0536	.038	.014	.005
		27	132	11.78	.4299	.1693	.0556	.036	.014	.004
		30	134	13.22	.4529	.1804	.0580	.034	.013	.004
TRIPLE SCREW 1:2:1	CENTER SCREW D = 23.00	21	128	8.619	1.795	.207	.0674	.208	.024	.0078
		24	131	9.824	1.849	.213	.0693	.188	.021	.007
		27	133	11.76	1.903	.219	.0710	.161	.018	.006
		30	136	14.02	1.981	.227	.0735	.141	.016	.0524
	OUTBD SCREW D =	21	122	7.708	.2866	.1131	.0368	.037	.014	.005
		24	125	8.816	.3094	.1234	.0395	.035	.013	.004
		27	128	9.751	.3283	.1319	.0418	.034	.013	.004
		30	131	10.74	.3477	.1407	.0441	.032	.013	.004

TABLE 115 RELATIVE VIBRATORY FORCE AT BOLLARD CONDITION

CASE I PROPELLER TYPE B-3.65 N= 120 RPM

ARRANGEMENT AND DIAMETER, FT		TOTAL SHP 10^3 x	PITCH-DIAMETER RATIO	THRUST 10^4 LBS	FORCE, 10^4 LBS			(FORCE / THRUST) %		
					CLEARANCE / DIA.			CLEARANCE / DIA		
					0.1	0.3	0.6	0.1	0.3	0.6
TWIN SCREW D= 18.9		15	.445	18.2	.491	307	.108	2.70	1.69	.60
		30	.705	29.2	.778	.485	.171	2.67	1.66	.58
		45	.871	37.6	.999	.623	.219	2.66	1.66	.58
TRIPLE SCREW 1:1:1	CENTER SCREW D= 14.93	15	.737	12.0	.468	.175	.041	3.90	1.46	.34
		30	1.052	18.3	.711	.267	.062	3.89	1.46	.34
		45	1.307	22.7	.882	.330	.077	3.88	1.46	.34
	OUTBD. SCREW D= 14.93	15	.737	12.0	.320	.199	.070	2.67	1.66	.58
		30	1.052	18.3	.486	.303	.106	2.65	1.65	.58
		45	1.307	22.7	.602	.375	.131	2.65	1.65	.58
TRIPLE SCREW 1:2:1	CENTER SCREW D= 16.56	15	.521	18.6	.733	.274	.065	3.94	1.47	.34
		30	.741	28.8	1.124	.421	.099	3.90	1.46	.34
		45	.910	X	—	—	—	—	—	—
	OUTBD. SCREW D= 13.12	15	.884	8.9	.236	.147	.058	2.66	1.66	.58
		30	1.275	13.2	.350	.218	.076	2.65	1.65	.58
		45	H	—	—	—	—	—	—	—

TABLE III RELATIVE VIBRATORY FORCE AT BOLLARD CONDITION

CASE II PROPELLER TYPE B-3.65 N= 120 RPM

ARRANGEMENT AND DIAMETER, FT		TOTAL SHP 10^3 x	PITCH-DIAMETER RATIO	THRUST 10^4 LBS	FORCE, 10^4 LBS CLEARANCE / DIA.			(FORCE / THRUST)% CLEARANCE / DIA		
					0.1	0.3	0.6	0.1	0.3	0.6
TWIN SCREW D= 21.6		30	.502	32.3	.870	.544	.192	2.69	1.68	.59
		45	.621	42.9	1.146	.715	.252	2.67	1.67	.59
		60	.715	50.7	1.351	.843	.296	2.66	1.66	.58
TRIPLE SCREW 1:1:1	CENTER SCREW D= 17.07	30	.747	20.8	.812	.304	.071	3.90	1.46	.34
		45	.916	26.7	1.039	.389	.091	3.89	1.46	.34
		60	1.064	31.7	1.232	.462	.107	3.89	1.46	.34
	OUTBD. SCREW D= 17.07	30	.747	20.8	.554	.345	.121	2.66	1.66	.58
		45	.916	26.7	.709	.442	.155	2.66	1.66	.58
		60	1.064	31.7	.841	.524	.184	2.65	1.65	.58
TRIPLE SCREW 1:2:1	CENTER SCREW D= 21.21	30	.528	32.3	1.272	.476	.113	3.94	1.47	.35
		45	.649	42.0	1.643	.615	.145	3.91	1.47	.34
		60	.752	50.0	1.951	.731	.171	3.90	1.46	.34
	OUTBD. SCREW D= 15.0	30	.894	15.0	.399	.248	.087	2.66	1.66	.58
		45	1.103	19.6	.520	.324	.114	2.65	1.65	.58
		60	1.291	22.8	.604	.377	.132	2.65	1.65	.58

TABLE-IX RELATIVE VIBRATORY FORCE AT BOLLARD CONDITION.

CASE II PROPELLER TYPE B-3.65 N = 120 RPM

ARRANGEMENT	AND DIAMETER, FT	TOTAL SHP $10^3 \times$	PITCH-DIAMETER RATIO	THRUST 10^4 LBS	FORCE, 10^4 LBS			(FORCE / THRUST) %		
					CLEARANCE / DIA.			CLEARANCE / DIA		
					0.1	0.3	0.6	0.1	0.3	0.6
TWIN SCREW	D = 23.0	30	L	—	—	—	—	—	—	—
		45	.528	44.7	1.201	.750	.265	2.69	1.68	.59
		60	.613	54.2	1.449	.904	.3189	2.67	1.67	.59
TRIPLE SCREW 1:1:1	CENTER SCREW D = 19.2	30	.555	23.2	.912	.341	.081	3.93	1.47	.35
		45	.679	29.7	1.161	.435	.102	3.91	1.46	.34
		60	.791	35.7	1.392	.521	.122	3.90	1.46	.34
	OUTBD. SCREW D = 19.2	30	.555	23.2	.622	.388	.137	2.68	1.67	.59
		45	.679	29.7	.792	.494	.174	2.67	1.66	.59
		60	.791	35.7	.950	.592	.208	2.66	1.66	.58
TRIPLE SCREW 1:2:1	CENTER SCREW D = 23.0	30	L	—	—	—	—	—	—	—
		45	.528	44.7	1.760	.659	.157	3.94	1.47	.35
		60	.613	54.2	2.123	.795	.188	3.92	1.47	.35
	OUTBD. SCREW D = 16.27	30	.664	X	—	—	—	—	—	—
		45	.895	21.3	.566	.353	.124	2.66	1.66	.58
		60	.945	25.5	.677	.422	.148	2.65	1.65	.58

L - P/D < 0.5

X = IMPOSSIBLE ARRANGEMENT, AS C.S HAS TOO LOW P/D RATIO.

TABLE 16 RELATIVE VIBRATORY FORCE AT BOLLARD CONDITION

CASE I PROPELLER TYPE B-4.70 N = 120 RPM

ARRANGEMENT AND DIAMETER, FT		TOTAL SHP 10^3 x	PITCH-DIAMETER RATIO	THRUST 10^4 LBS	FORCE, 10^4 LBS			(FORCE / THRUST), %		
					CLEARANCE / DIA.			CLEARANCE / DIA		
					0.1	0.3	0.6	0.1	0.3	0.6
TWIN SCREW D = 19.9		15	L	—	—	—	—	—	—	—
		30	.718	31.3	.1697	.135	.0136	.542	.43	.04
		45	.881	39.6	.2141	.171	.017	.541	.43	.04
TRIPLE SCREW 1:1:1	CENTER SCREW D = 14.93	15	.748	12.8	.183	.0197	~0	1.43	.15	~0
		30	1.045	18.8	.267	.0289	~0	1.42	.15	~0
		45	1.257	23.7	.337	.036	~0	1.42	.15	~0
	OUTBD. SCREW D = 14.93	15	.748	12.8	.069	.055	.005	.54	.43	.04
		30	1.045	18.8	.101	.081	.008	.54	.43	.04
		45	1.257	23.7	.128	.102	.010	.54	.43	.04
TRIPLE SCREW 1:2:1	CENTER SCREW D = 18.56	15	.517	19.5	.281	.030	~0	1.44	.15	~0
		30	.752	30.7	.438	.047	~0	1.43	.15	~0
		45	.921	X	—	—	—	—	—	—
	OUTBD. SCREW D = 13.12	15	.896	9.4	.051	.040	.004	.54	.43	.04
		30	1.231	13.8	.074	.059	.006	.54	.43	.04
		45	H	—	—	—	—	—	—	—

H = $P/D > 1.4$

X = ARRANGEMENT IMPOSSIBLE, DUE TO OUT-OF-RANGE OUTBOARD SCREW P/D RATIO

TABLE 117 RELATIVE VIBRATORY FORCE AT BOLLARD CONDITION

CASE II PROPELLER TYPE B-4.70 N= 120 RPM

ARRANGEMENT AND DIAMETER, FT		TOTAL SHP 10^3 x	PITCH-DIAMETER RATIO	THRUST 10^4 LBS	FORCE, 10^4 LBS CLEARANCE / DIA.			(FORCE / THRUST) % CLEARANCE / DIA		
					0.1	0.3	0.6	0.1	0.3	0.6
TWIN SCREW D= 21.6		30	.499	34.6	.189	.151	.015	.55	.44	.04
		45	.624	44.5	.242	.193	.019	.54	.43	.04
		60	.728	54.3	.294	.234	.024	.54	.43	.04
TRIPLE SCREW 1:1:1	CENTER SCREW D= 17.07	30	.757	22.1	.316	.034	≅0	1.43	.15	≅0
		45	.926	28.0	.399	.043	≅0	1.42	.15	≅0
		60	1.057	32.5	.462	.050	≅0	1.42	.15	≅0
	OUTBD. SCREW D= 17.07	30	.757	22.1	.120	.095	.010	.54	.43	.04
		45	.926	28.0	.151	.121	.012	.54	.43	.04
		60	1.057	32.5	.175	.140	.014	.54	.43	.04
TRIPLE SCREW 1:2:1	CENTER SCREW D= 21.21	30	.524	33.6	.484	.052	≃0	1.44	.16	≃0
		45	.656	44.0	.630	.068	≃0	1.43	.15	≃0
		60	.761	53.2	.759	.082	≃0	1.43	.15	≃0
	OUTBD. SCREW D= 15.0	30	.906	16.2	.088	.070	.007	.54	.43	.04
		45	1.092	20.2	.109	.0869	.009	.54	.43	.04
		60	1.244	23.8	.128	.1023	.010	.54	.43	.04

TABLE H8 RELATIVE VIBRATORY FORCE AT BOLLARD CONDITION

CASE II PROPELLER TYPE B-4.70 N= 120 RPM

ARRANGEMENT AND DIAMETER, FT		TOTAL SHP 10^3 x	PITCH-DIAMETER RATIO	THRUST 10^4 LBS	FORCE, 10^4 LBS			(FORCE / THRUST) %		
					CLEARANCE / DIA.			CLEARANCE / DIA		
					0.1	0.3	0.6	0.1	0.3	0.6
TWIN SCREW D= 23.0		30	L	—	—	—	—	—	—	—
		45	.525	46.5	.254	.202	.020	.55	.435	.04
		60	.615	56.1	.305	.243	.024	.54	.43	.04
TRIPLE SCREW 1:1:1	CENTER SCREW D= 19.2	30	.552	23.8	.342	.037	≅ 0	1.44	.16	≅ 0
		45	.690	31.7	.453	.049	≅ 0	1.43	.15	≅ 0
		60	.797	37.6	.536	.058	≅ 0	1.43	.15	≅ 0
	OUTBD. SCREW D= 19.2	30	.552	23.8	.130	.103	.010	.55	.43	.04
		45	.690	31.7	.172	.137	.014	.54	.43	.04
		60	.797	37.6	.204	.162	.016	.54	.43	.04
TRIPLE SCREW 1:2:1	CENTER SCREW D= 23.0	30	L	—	—	—	—	—	—	—
		45	.525	46.5	.670	.072	≅ 0	1.44	.16	≅ 0
		60	.615	56.1	.805	.087	≅ 0	1.43	.15	≅ 0
	OUTBD. SCREW D= 16.27	30	.673	X	—	—	—	—	—	—
		45	.907	22.5	.122	.097	.010	.54	.43	.04
		60	.952	26.2	.141	.113	.011	.54	.43	.04

L = P/D < 0.5

X - IMPOSSIBLE ARRANGEMENT, AS C.S P/D IS OUT-OF-RANGE

APPENDIX II: FIGURES.

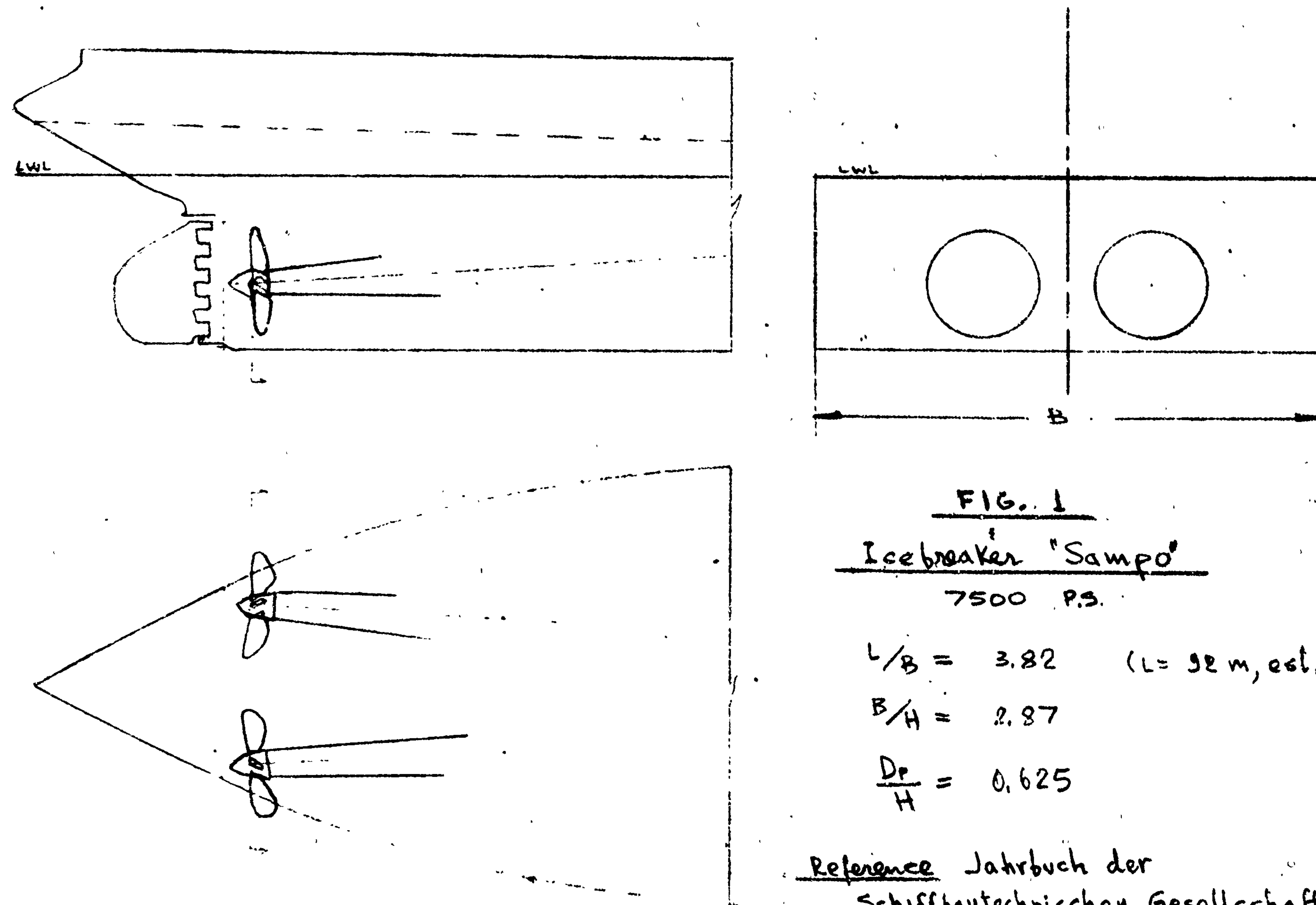


FIG. 1

Icebreaker "Sampo"

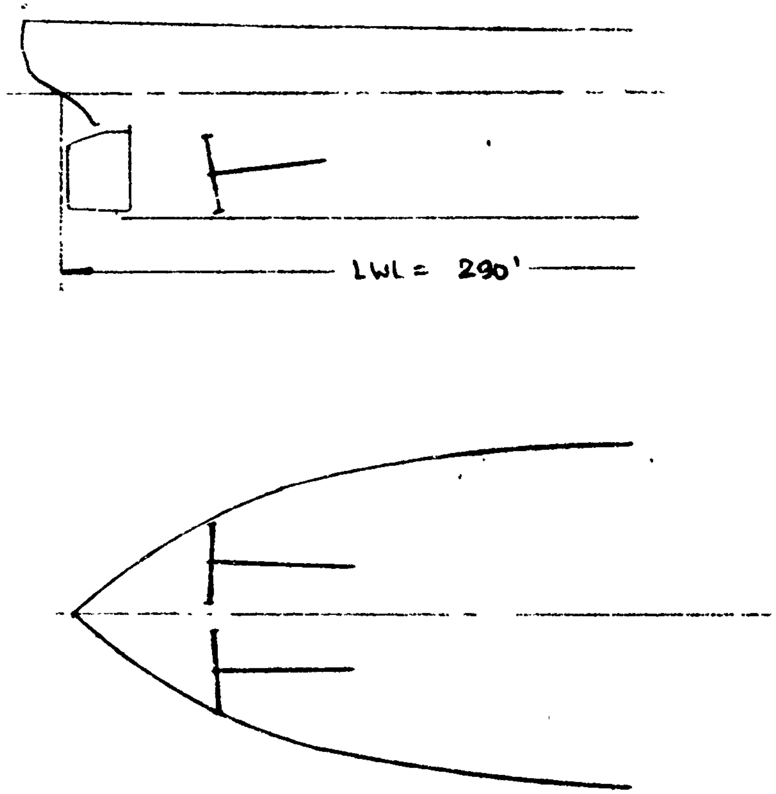
7500 P.S.

$L/B = 3.82$ (L = 92 m, est.)

$B/H = 2.87$

$\frac{D_P}{H} = 0.625$

Reference Jahrbuch der Schiffbautechnischen Gesellschaft, 1962 (P. 145)



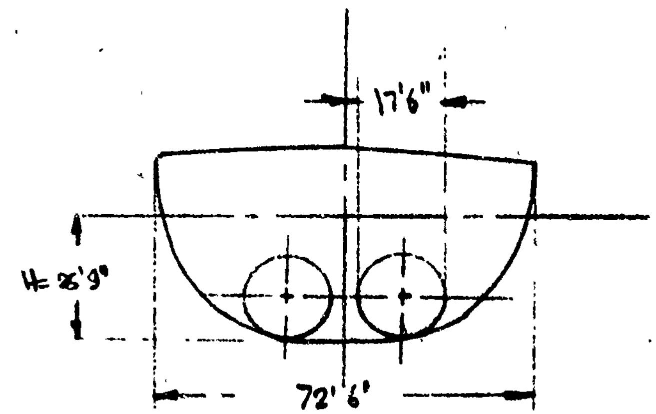


Fig. 2 Icebreaker USS 'Glacier'
(Ref. SNAME Trans. 1959)

L/B : 4.00
B/H : 2.82
D_p/H : 0.68
Displacement : 8640 L.T.
SHP_{max} : 21,000
speed : 16 knts.

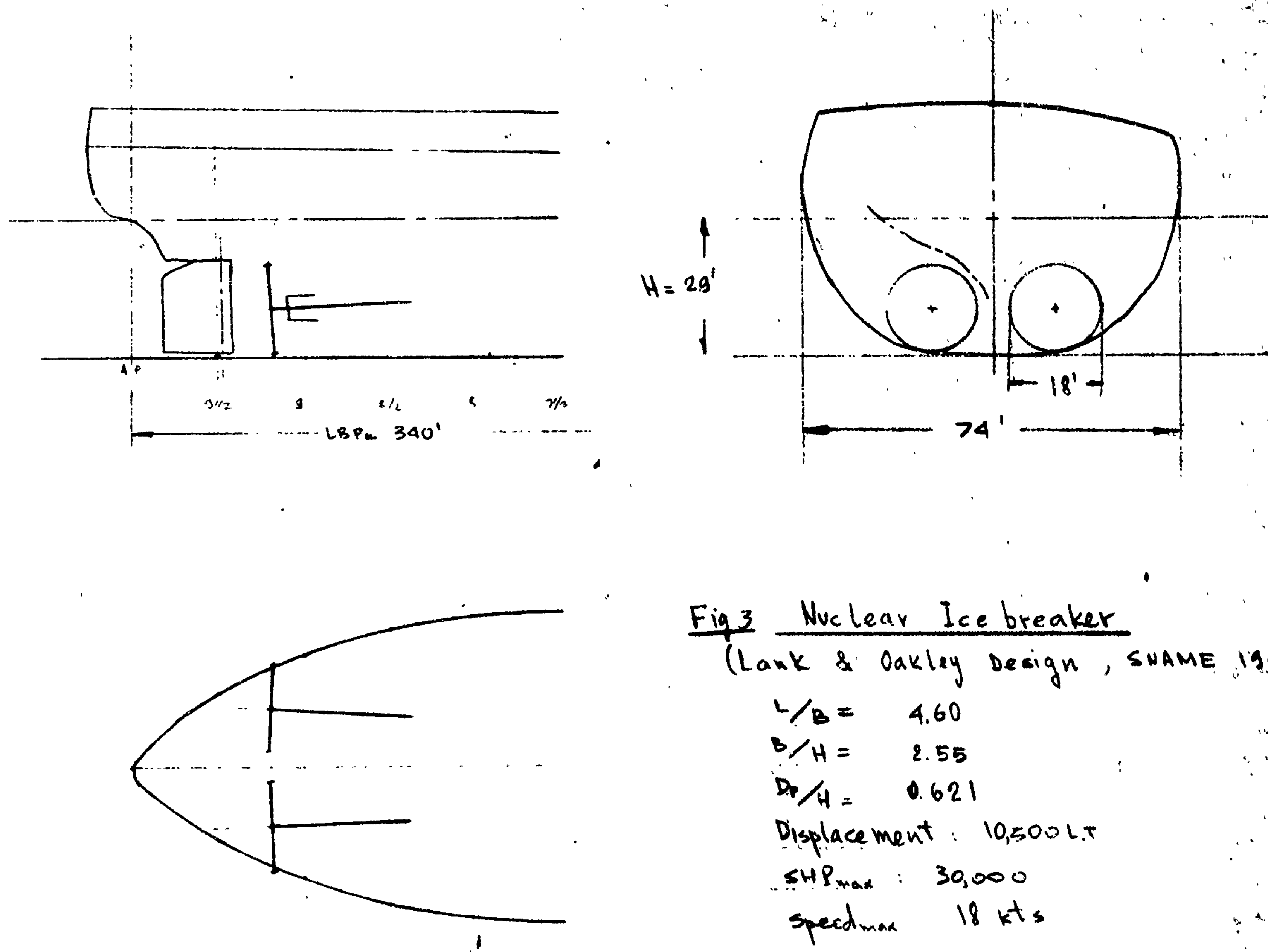


Fig 3 Nuclear Ice breaker
(Lank & Oakley Design, SNAME 1959)

$L/B =$ 4.60

$B/H =$ 2.55

$D_P/H =$ 0.621

Displacement : 10,500 LT

SHP_{max} : 30,000

$speed_{max}$ 18 kts

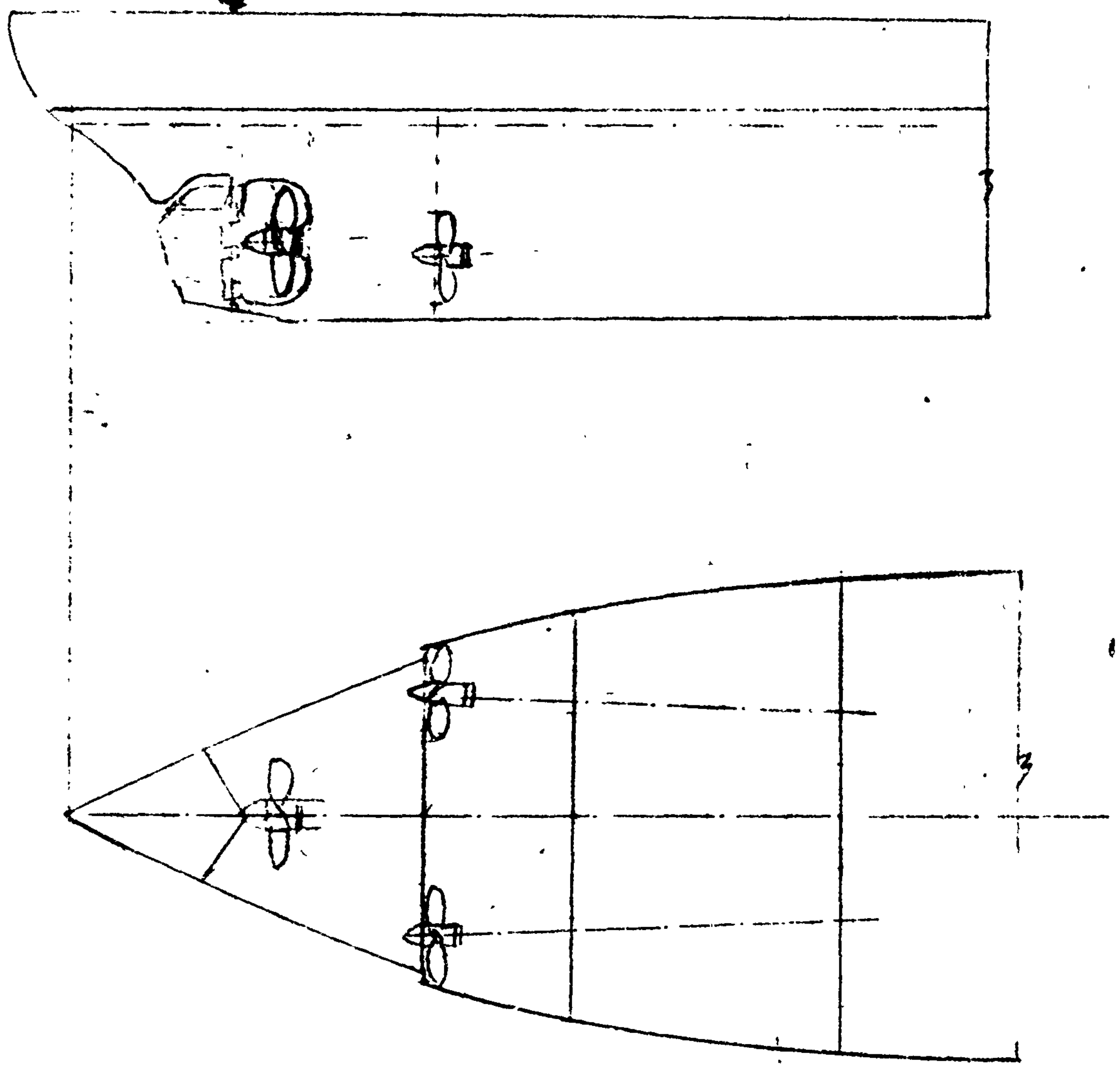


FIG. 4

SKETCH SHOWS THE GENERAL ARRGT OF TRIPLE SCREWS BASED ON THE "MOSCOW CLASS" ICE BREAKERS (U.S.S.R)

DIMENSIONS:

LENGTH O.A.	400' 7"
BEAM, max.	80'-4½"
DRAFT, max.	34'-5½"
DISPLACEMENT, max	15,360 tons (metric)
SHP, max	22,000
SPEED, max	18 kts

REFERENCE:
WÄRTSILÄ - KONCERNEN A/B
SANDVIKENS SKEPPSDOCKA.

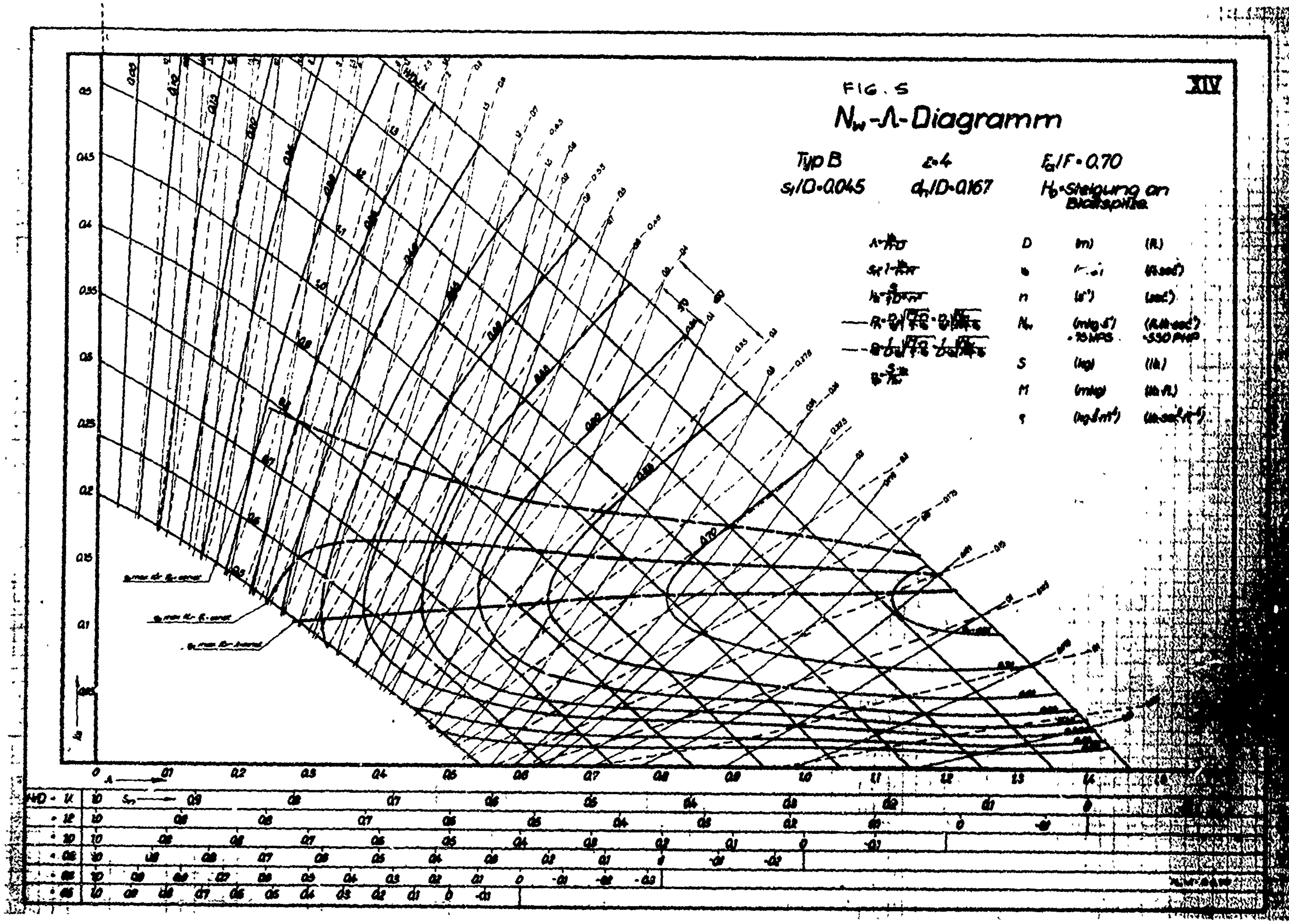


FIG. 5
XIV
N_w-Λ-Diagramm
Typ B
z=4
$F_a/F = 0.70$
$s_1/D = 0.045$
$d_n/D = 0.167$
H_b = Steigung an Blattspitze
D (m) (ft.)
n (s⁻¹) (sec⁻¹)
S (kg) (lb.)
M (mkg) (lb ft.)

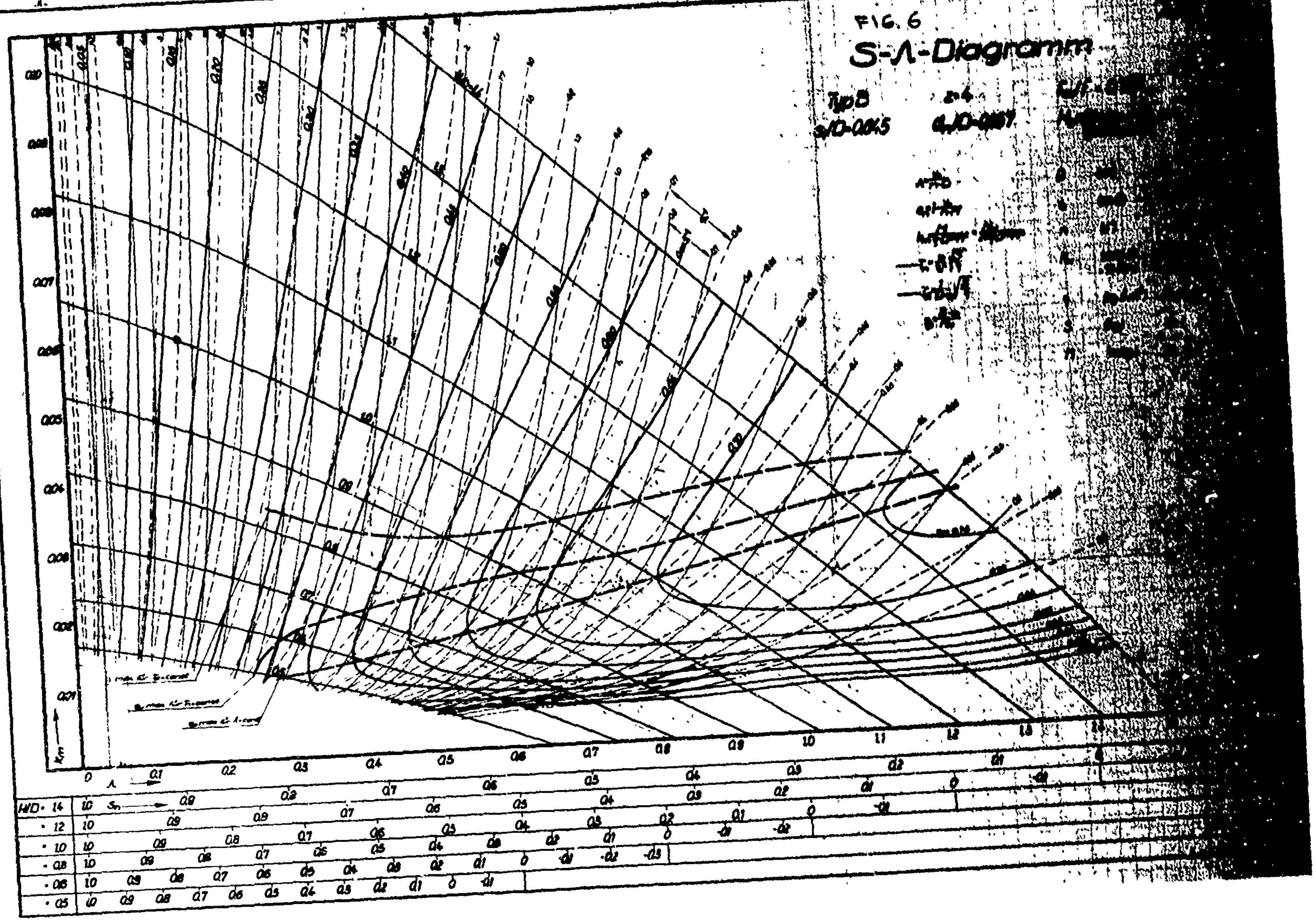


FIG. 6
S-Λ-Diagramm
Typ B
s/D-0.045
z=4

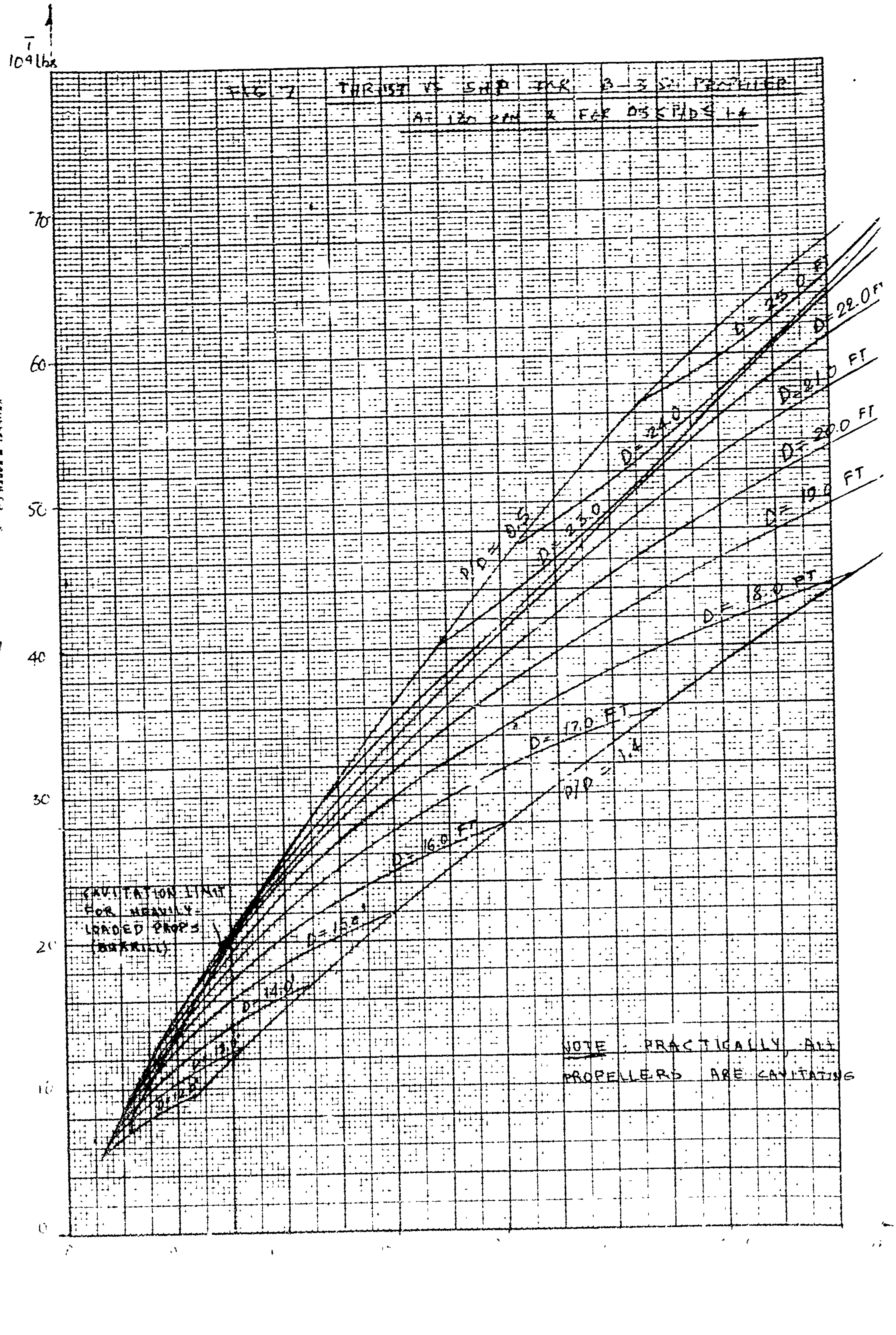
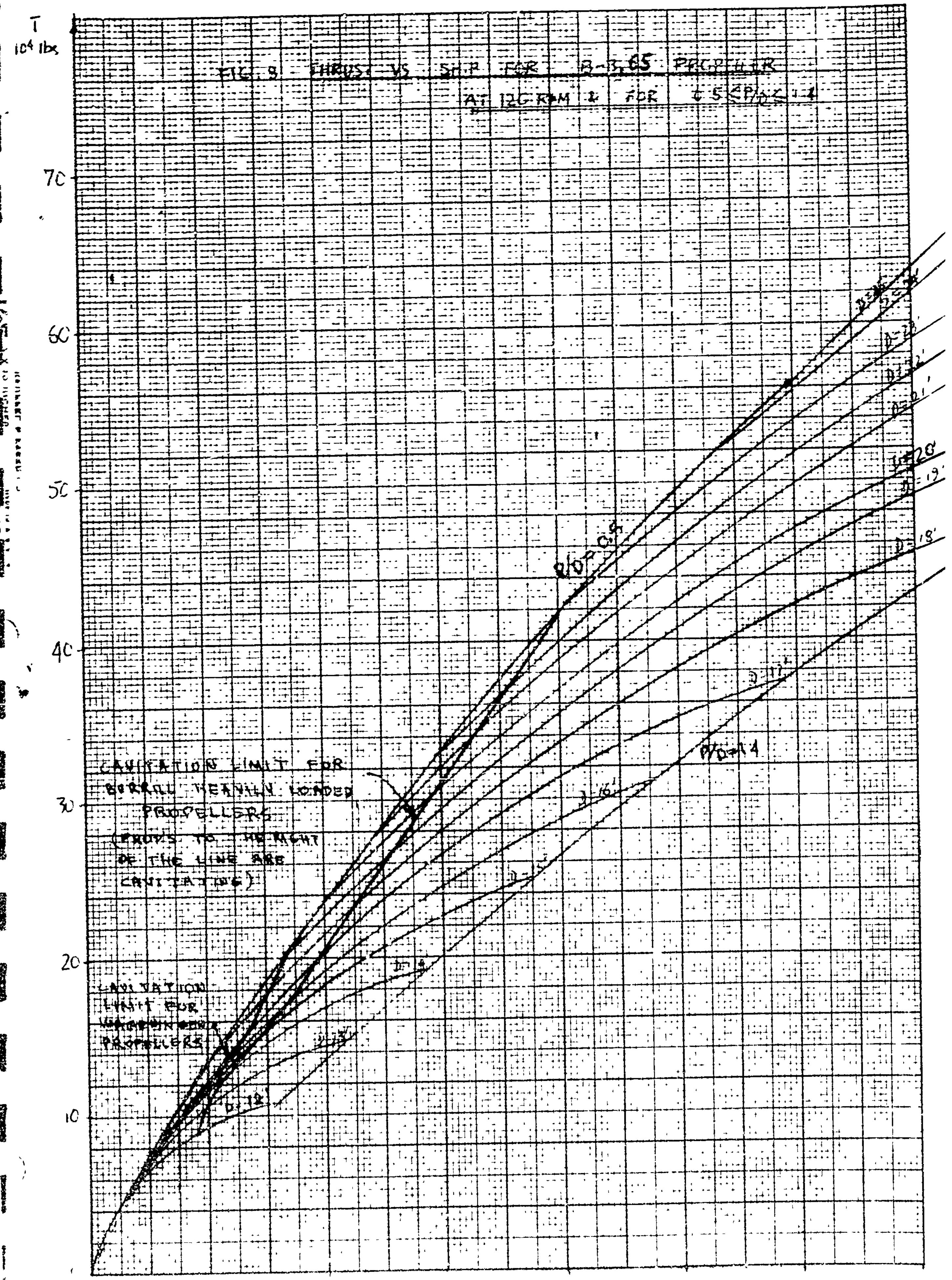


FIG 7 THRUST VS SHP FOR B-5 PROPELLER
AT 120 RPM & FOR 0.5 ≤ P/D ≤ 1.4
T
10^4 lbs
D = 25.0 FT
D = 22.0 FT
D = 24.0
D = 21.0 FT
D = 23.0
D = 20.0 FT
D = 19.0 FT
P/D = 0.5
D = 18.0 FT
D = 17.0 FT
P/D = 1.4
D = 16.0 FT
D = 15.0
D = 14.0
D = 13.0
D = 12.0
CAVITATION LIMIT FOR HEAVILY LOADED PROPS (BURRILL)
NOTE: PRACTICALLY ALL PROPELLERS ARE CAVITATING
70
60
50
40
30
20
10
0



T
10^4 lbs
70
60
50
40
30
20
10
FIG. 8 THRUST VS SHP FOR B-3.65 PROPELLER
AT 120 RPM & FOR .5 P/D .4
D=18'
D=20'
D=19'
D=17'
D=16'
D=14'
D=12'
P/D=1.4
CAVITATION LIMIT FOR BURRILL HEAVILY LOADED PROPELLERS (PROPS TO THE RIGHT OF THE LINE ARE CAVITATING)
CAVITATION LIMIT FOR MERCHANT PROPELLERS

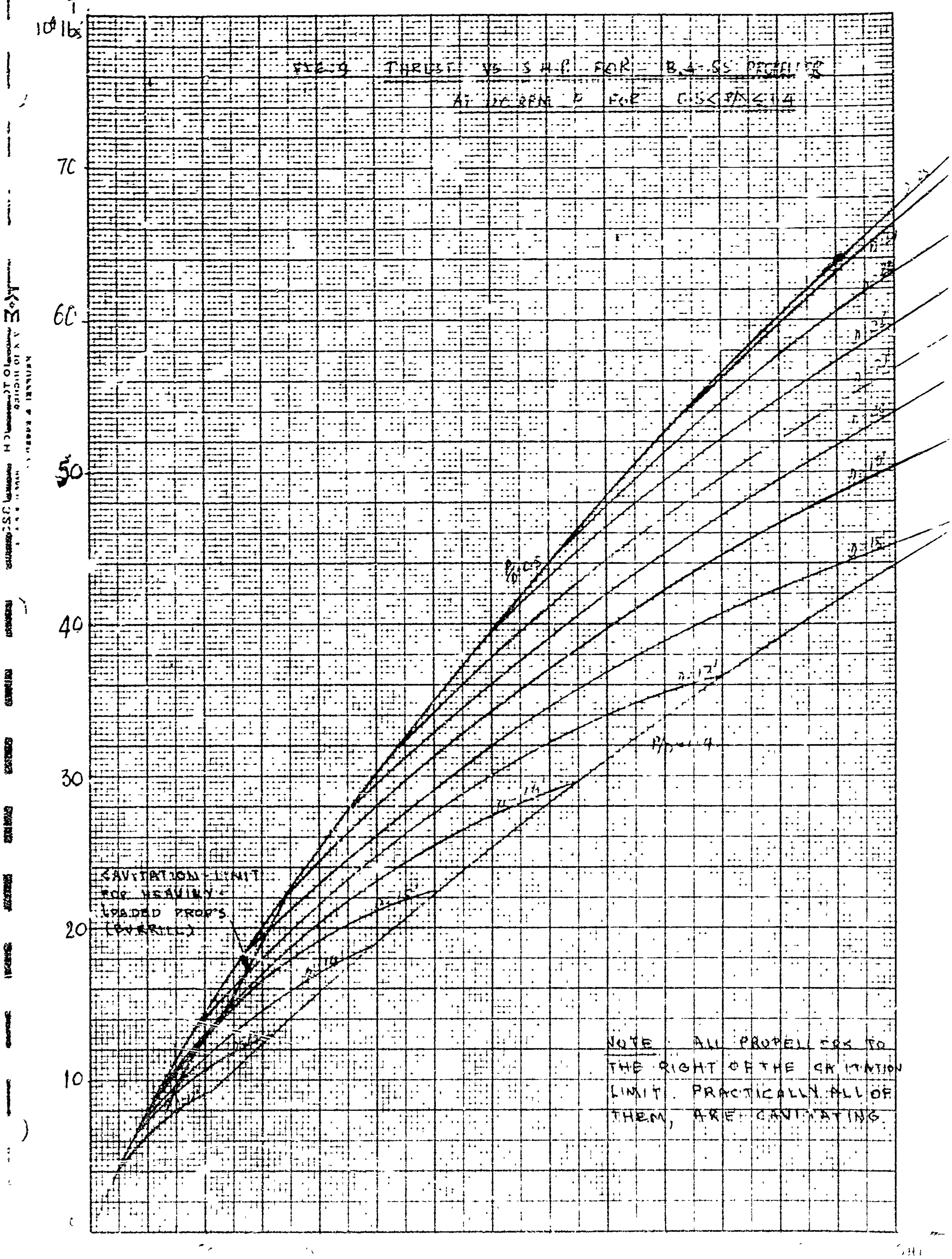
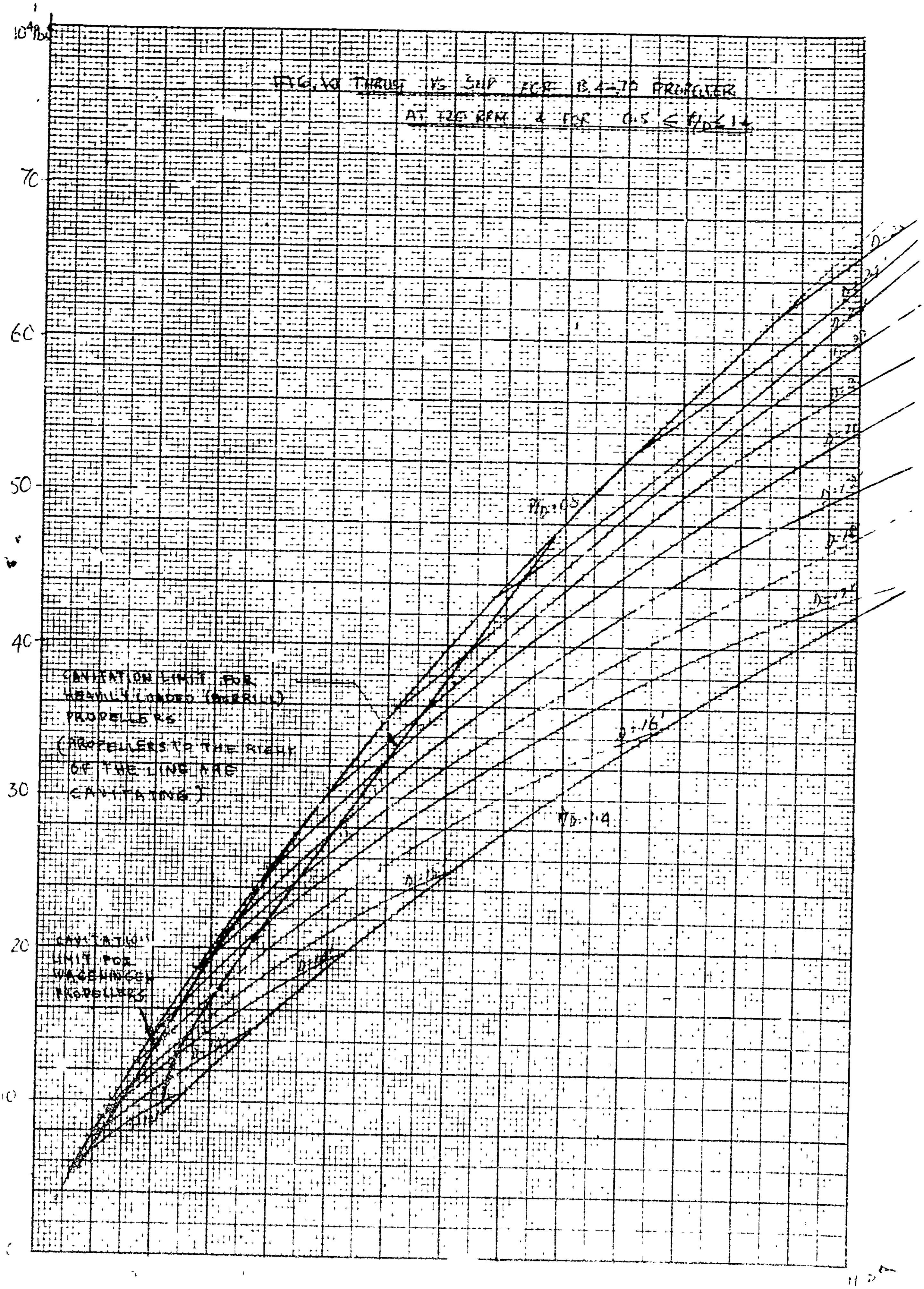


FIG 9 THRUST VS S.H.P. FOR B.4.55 PROPELLERS
T
10^3 lbs
70
60
50
40
30
20
10
CAVITATION LIMIT
FOR HEAVILY
LOADED PROP'S
(BURRILL)
NOTE ALL PROPELLERS TO
THE RIGHT OF THE CAVITATION
LIMIT PRACTICALLY ALL OF
THEM, ARE CAVITATING.


THRUST VS SLIP FOR B.4-70 PROPELLER
AT RPM FOR 0.5 ≤ P/D ≤ 1.4
70
60
50
40
30
20
CAVITATION LIMIT FOR
PROPELLERS
(PROPELLERS TO THE RIGHT
OF THE LINE ARE
CAVITATING)
LIMIT FOR
PROPELLERS

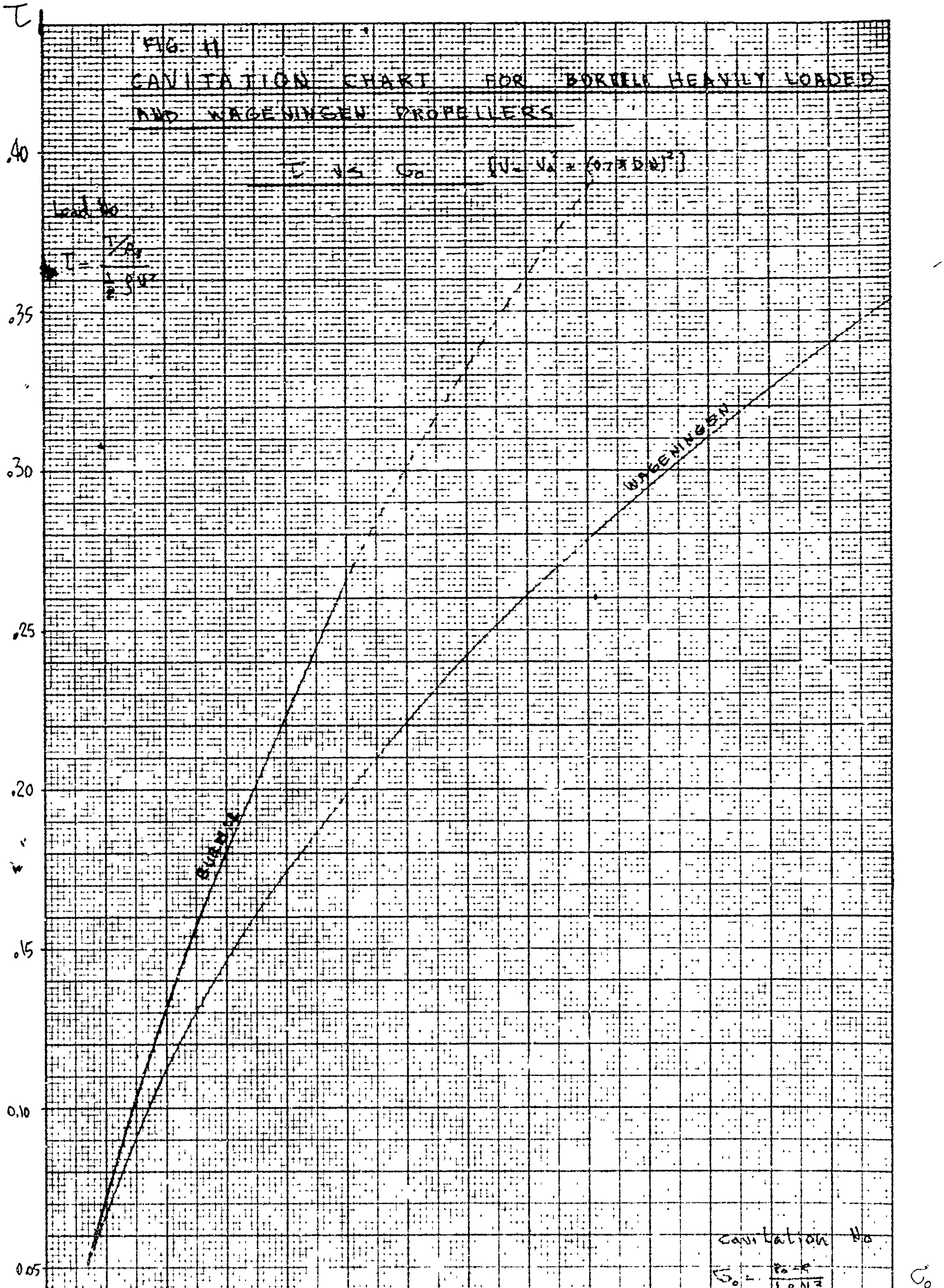


FIG. 11
CAVITATION CHART FOR BORTELL HEAVILY LOADED AND WAGENINGEN PROPELLERS
τ VS σ₀
Load No
τ
.40
.35
.30
.25
.20
.15
0.10
0.05
WAGENINGEN
Cavitation No
σ₀
0
.1
.2
.3
.4
.5
.6
.7
.8
1.0
1.2
1.3
1.4

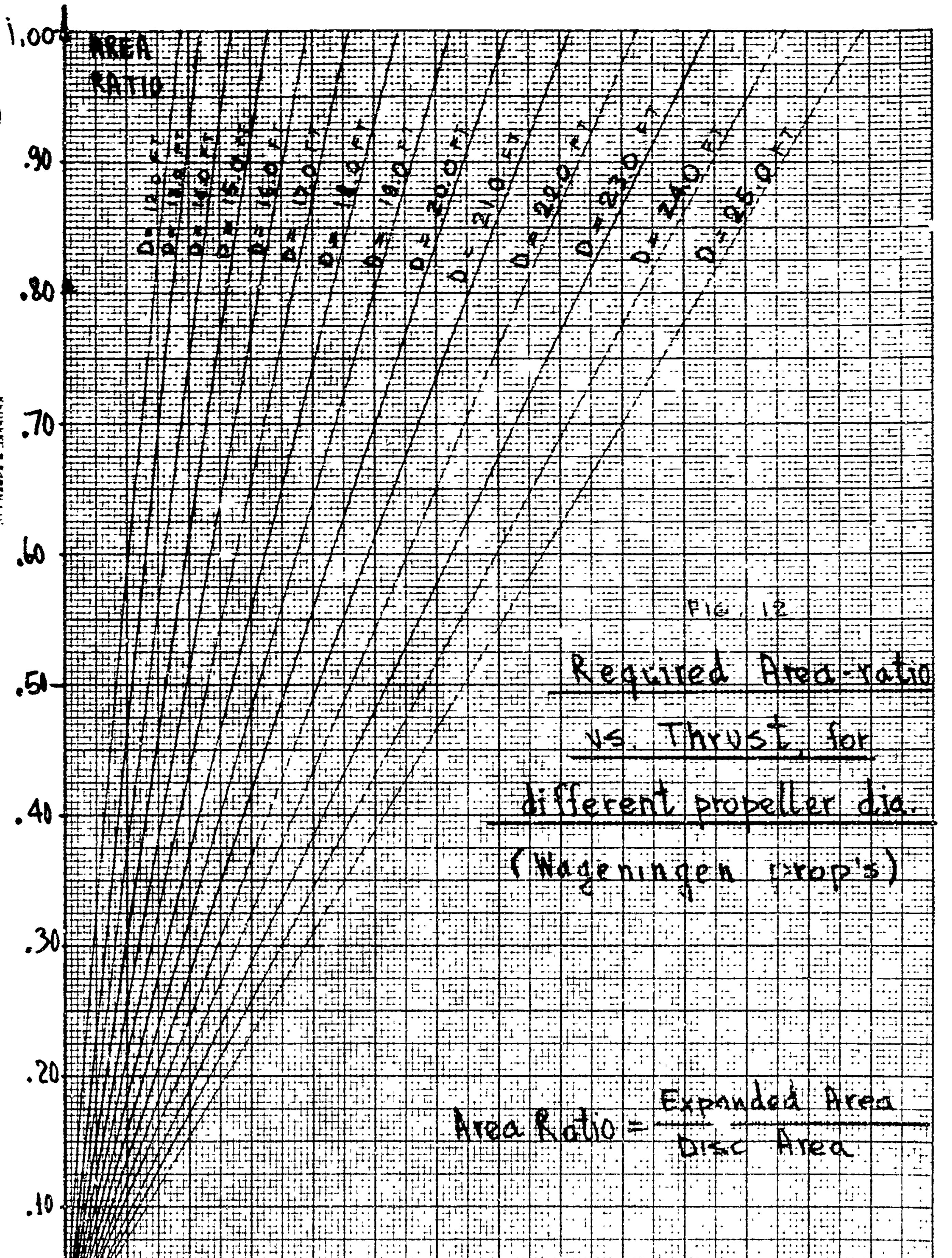
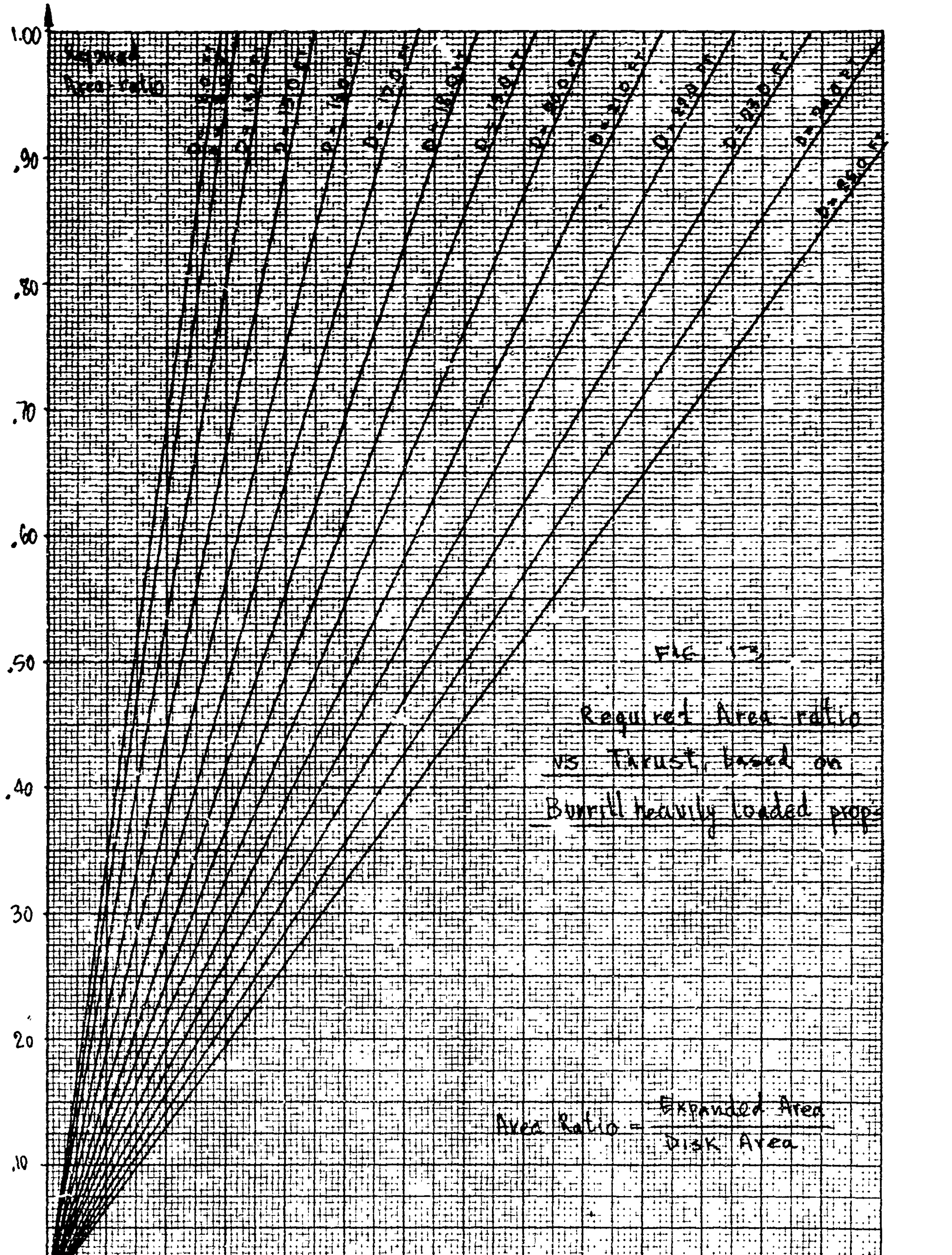
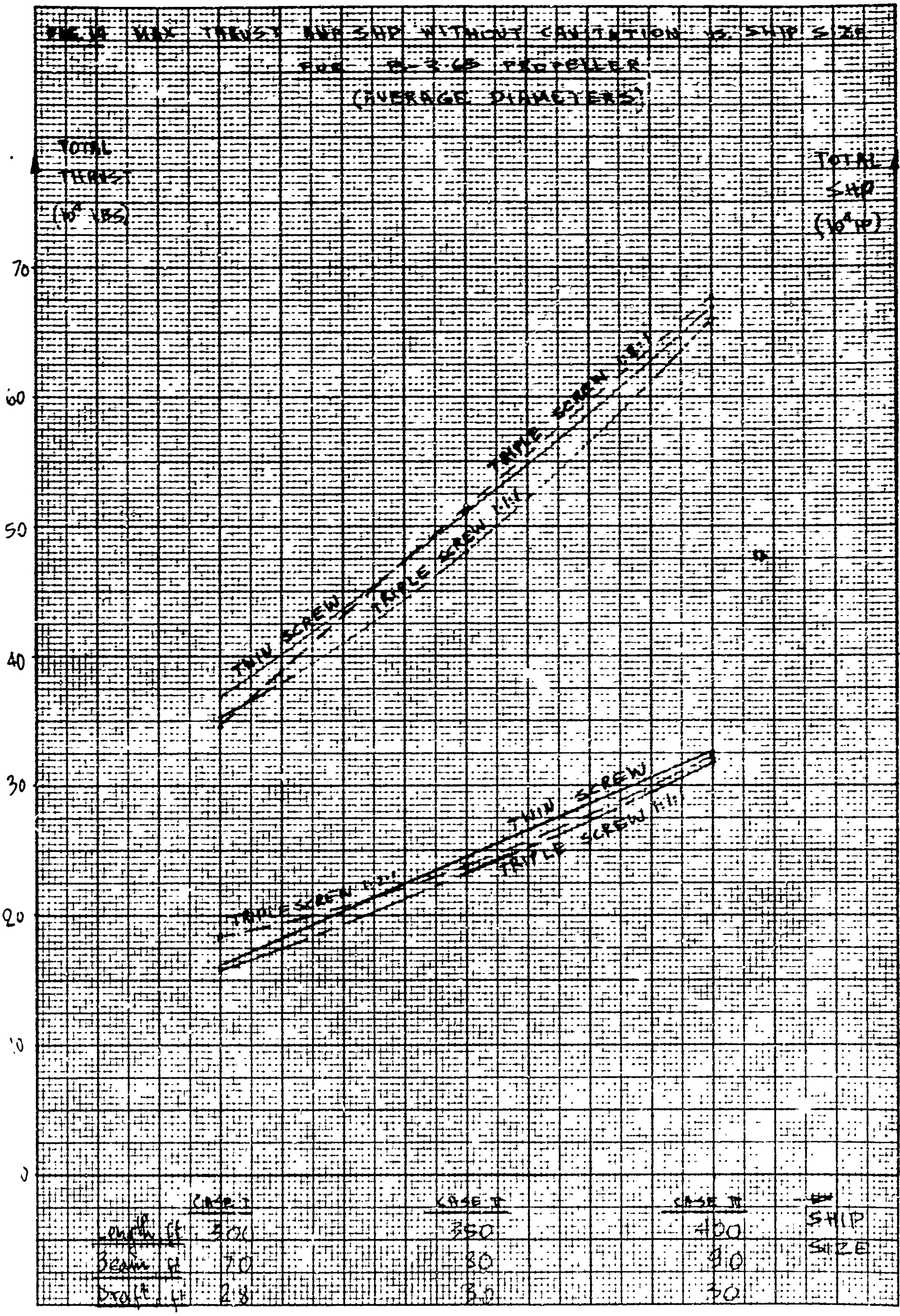


FIG. 12

Required Area-ratio vs Thrust, for different propeller dia. (Wageningen prop's)

$$\text{Area Ratio} = \frac{\text{Expanded Area}}{\text{Disc Area}}$$




MAX THRUST AND SHP WITHOUT CAVITATION VS. SHIP SIZE
FOR B-3.65 PROPELLER
(AVERAGE DIAMETERS)
TOTAL THRUST (10^3 LBS)
TOTAL SHP (10^4 HP)
70
60
50
40
30
20
10
0
5.0
4.0
3.0
2.0
1.0
TWIN SCREW
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:1:1
TWIN SCREW
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:1:1
CASE I
CASE II
CASE III
SHIP SIZE
Length ft 300 350 400
Beam ft 70 80 90
Draft ft 28 35 30

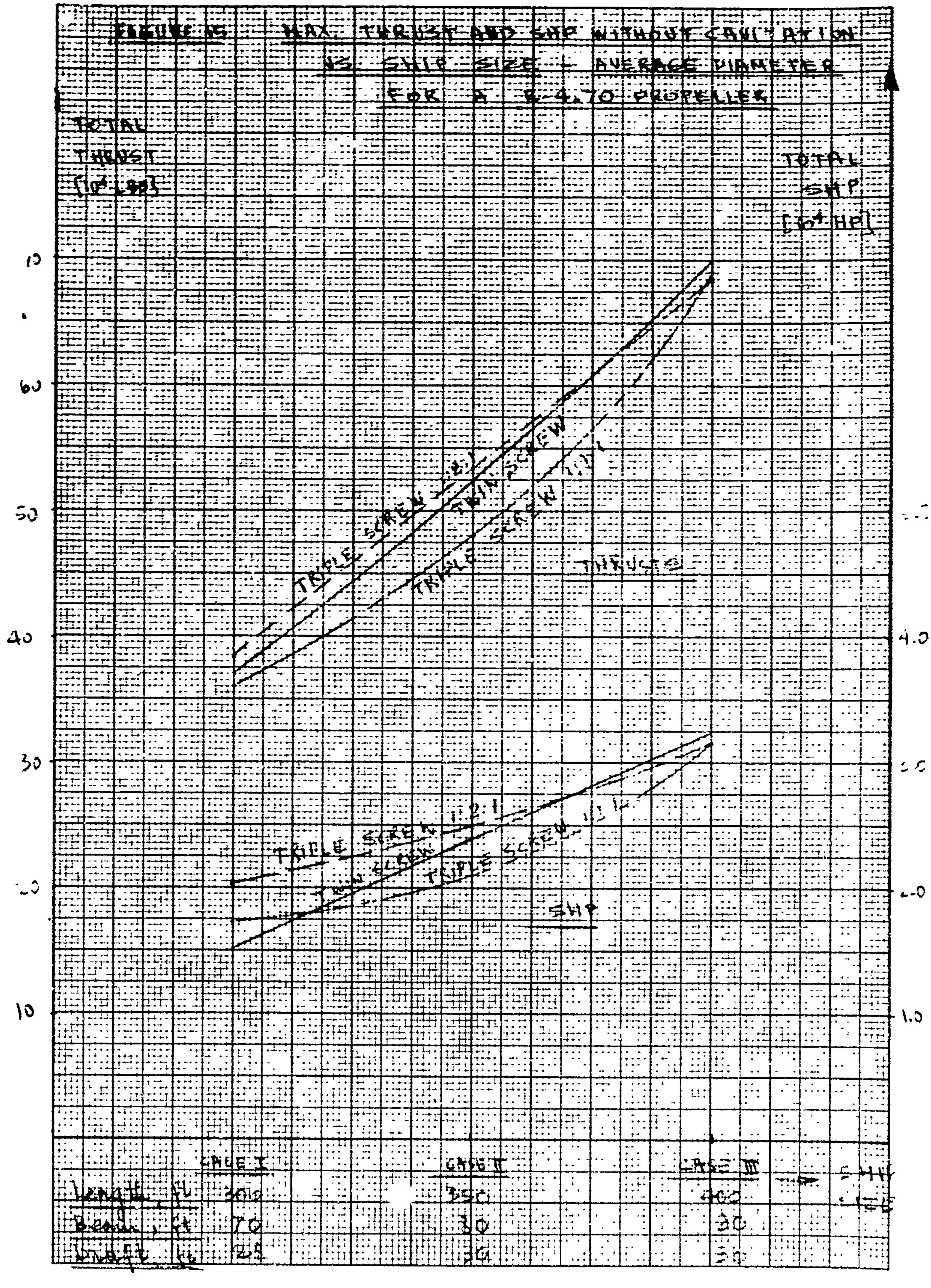


FIGURE 15 MAX. THRUST AND SHP WITHOUT CAVITATION VS. SHIP SIZE + AVERAGE DIAMETER FOR A B-4.70 PROPELLER

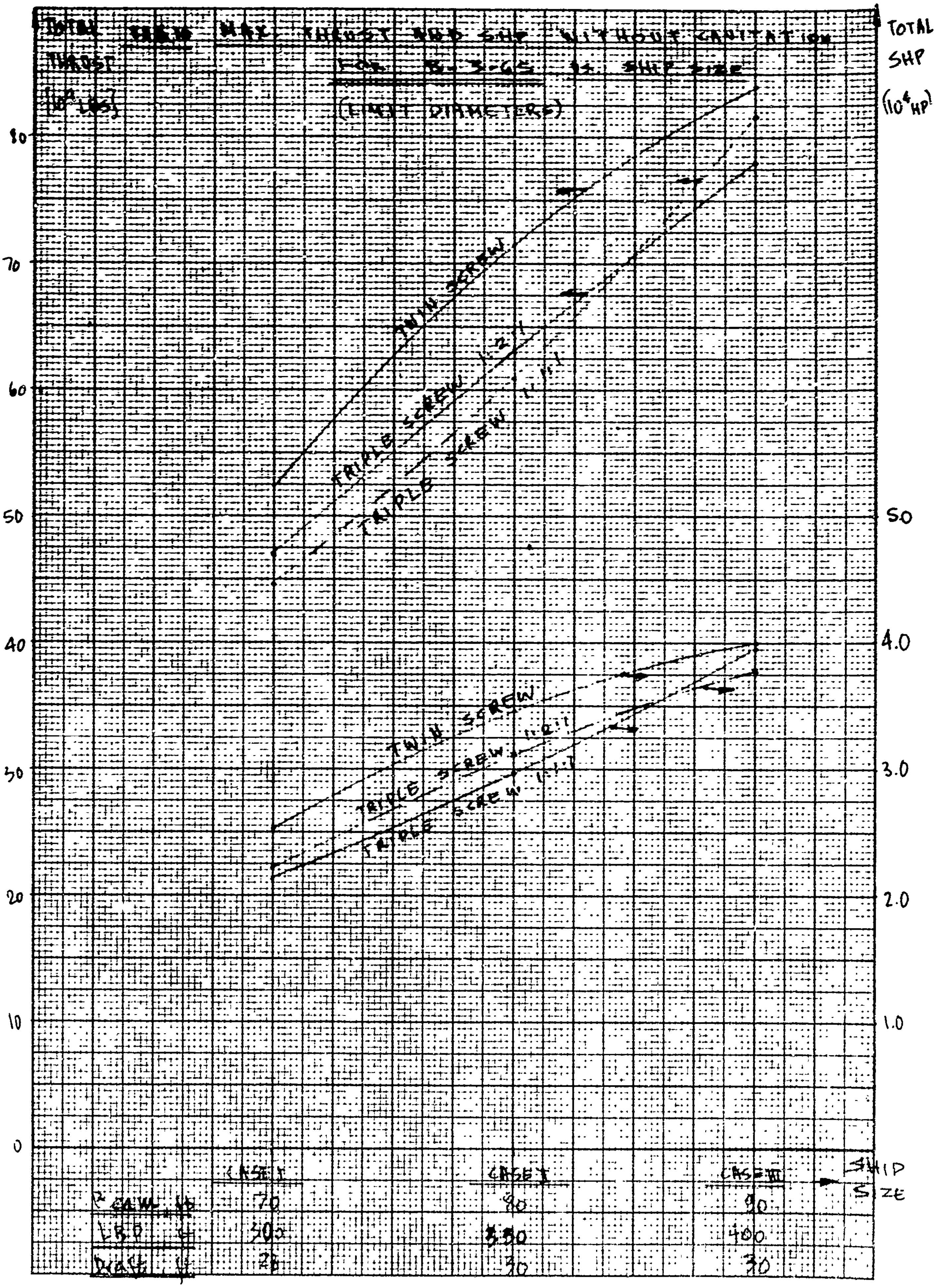
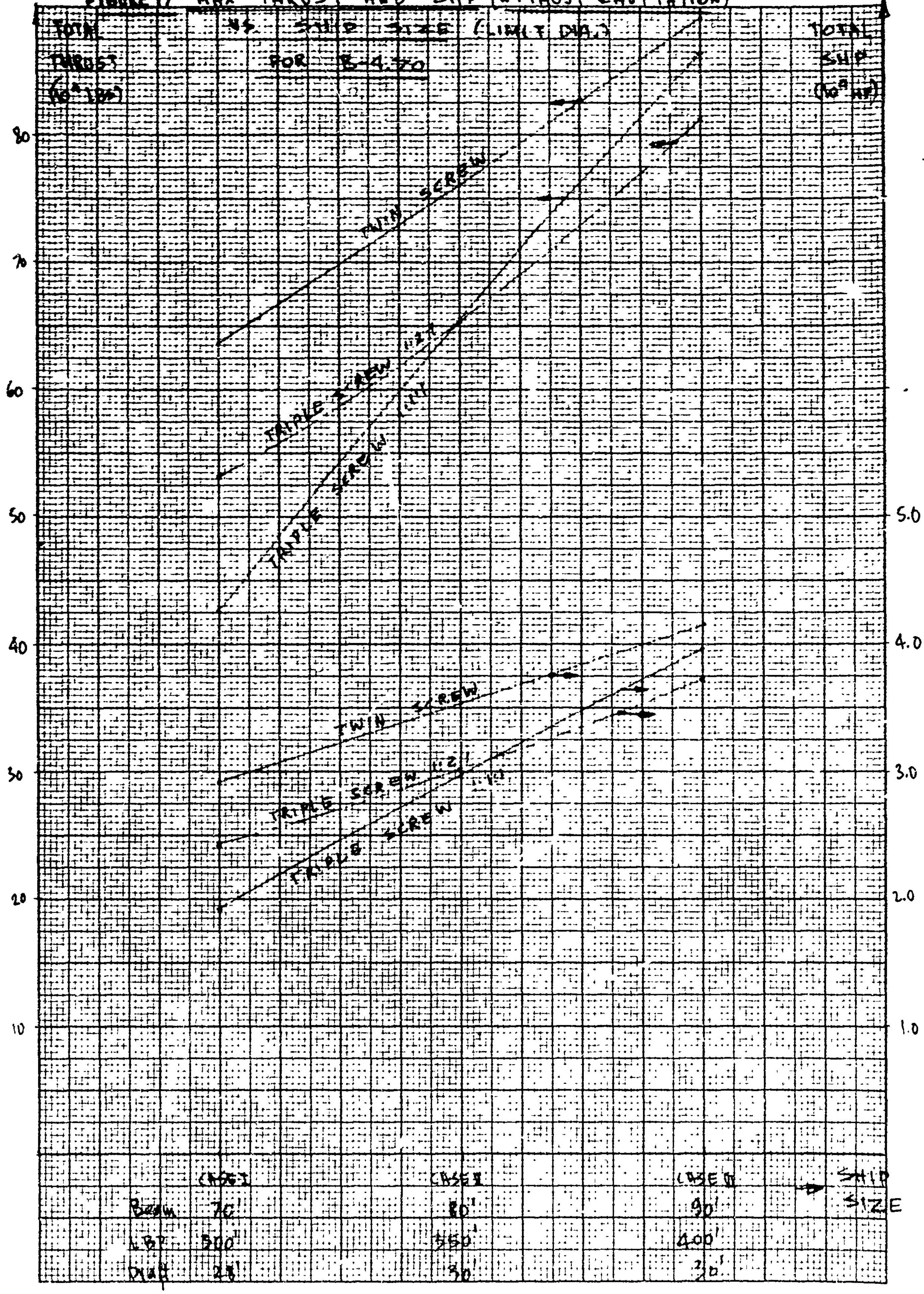
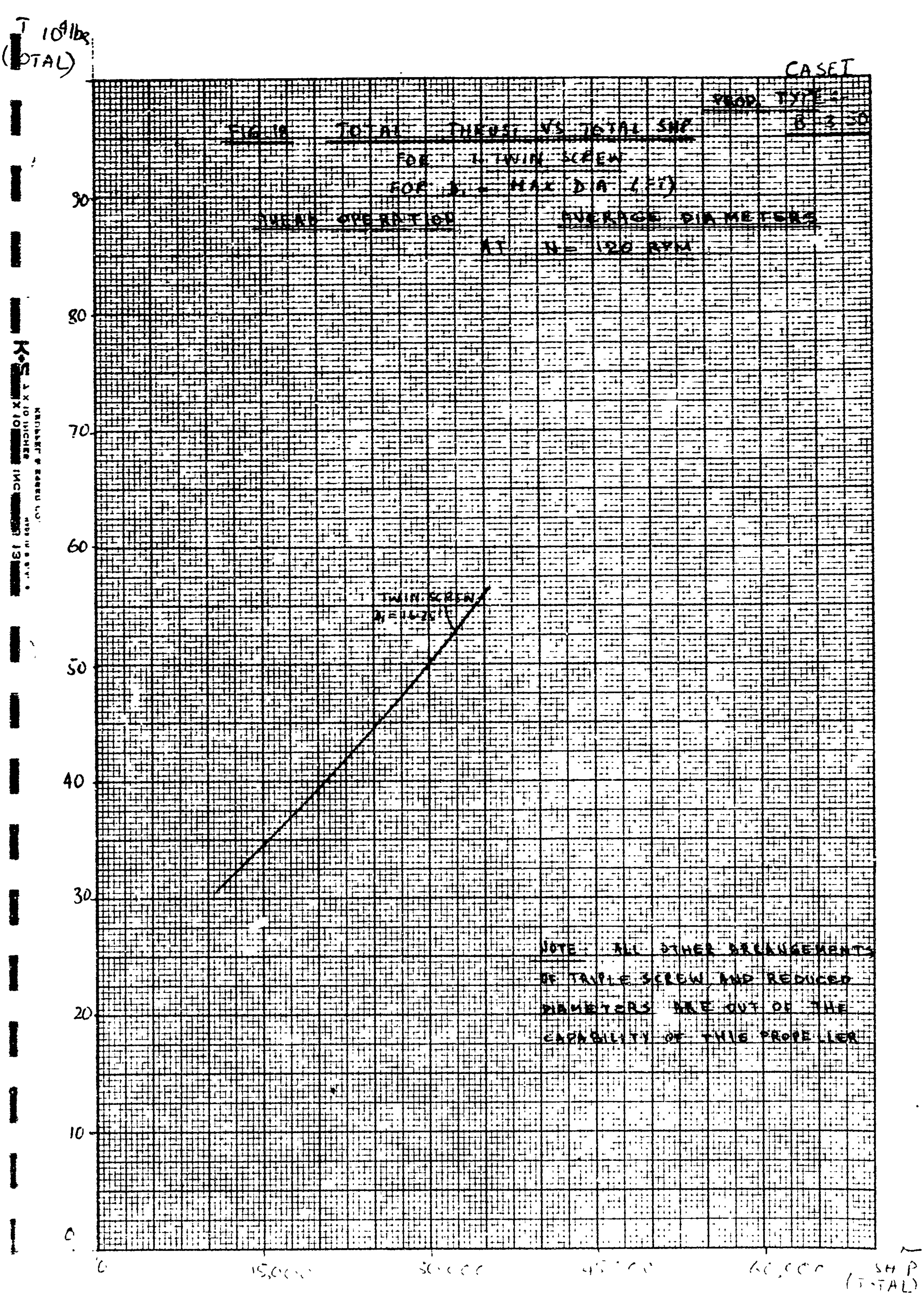
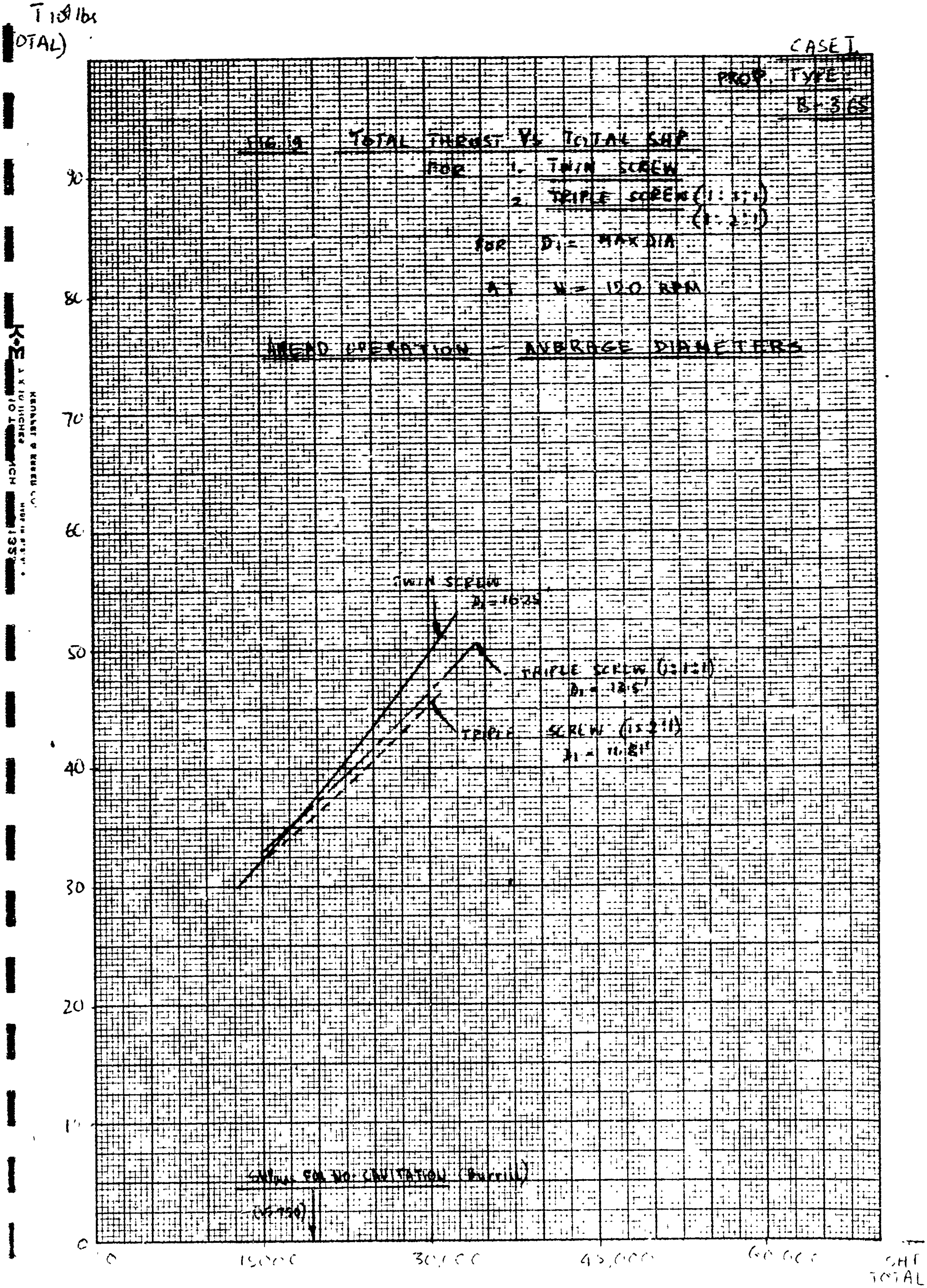

MAX. THRUST AND SHP WITHOUT CAVITATION
FOR 15-3-65 vs. SHIP SIZE
(LIMIT DIAMETERS)
TOTAL THRUST
TOTAL SHP
(10⁴ HP)
80
70
60
50
40
30
20
10
0
5.0
4.0
3.0
2.0
1.0
TWIN SCREW
TRIPLE SCREW 1.2:1
TRIPLE SCREW 1:1:1
CASE I
CASE II
CASE III
SHIP SIZE
70
80
90
300
350
400
28
30
30

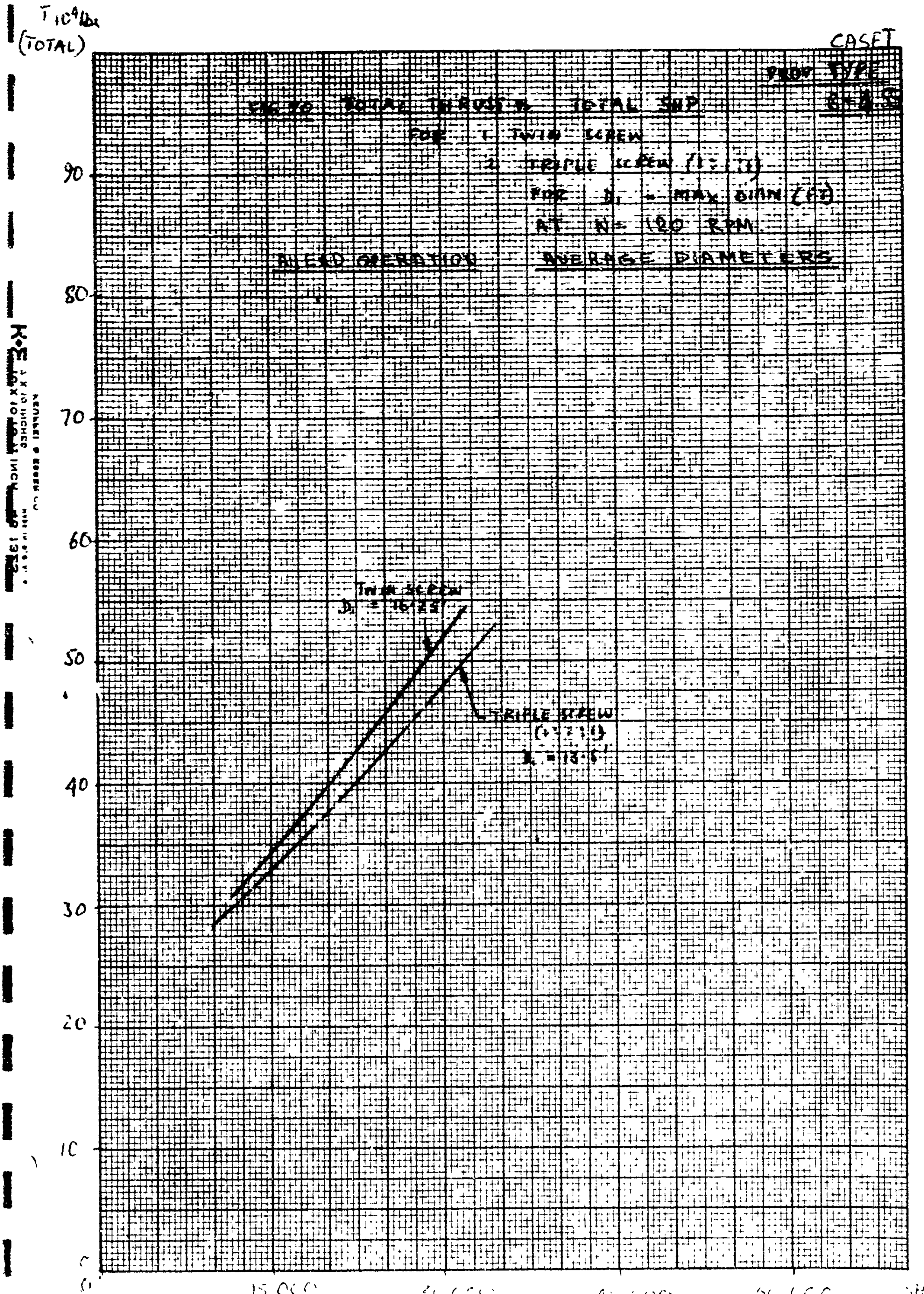
FIGURE 17 MAX THRUST AND SHP (WITHOUT CAVITATION)



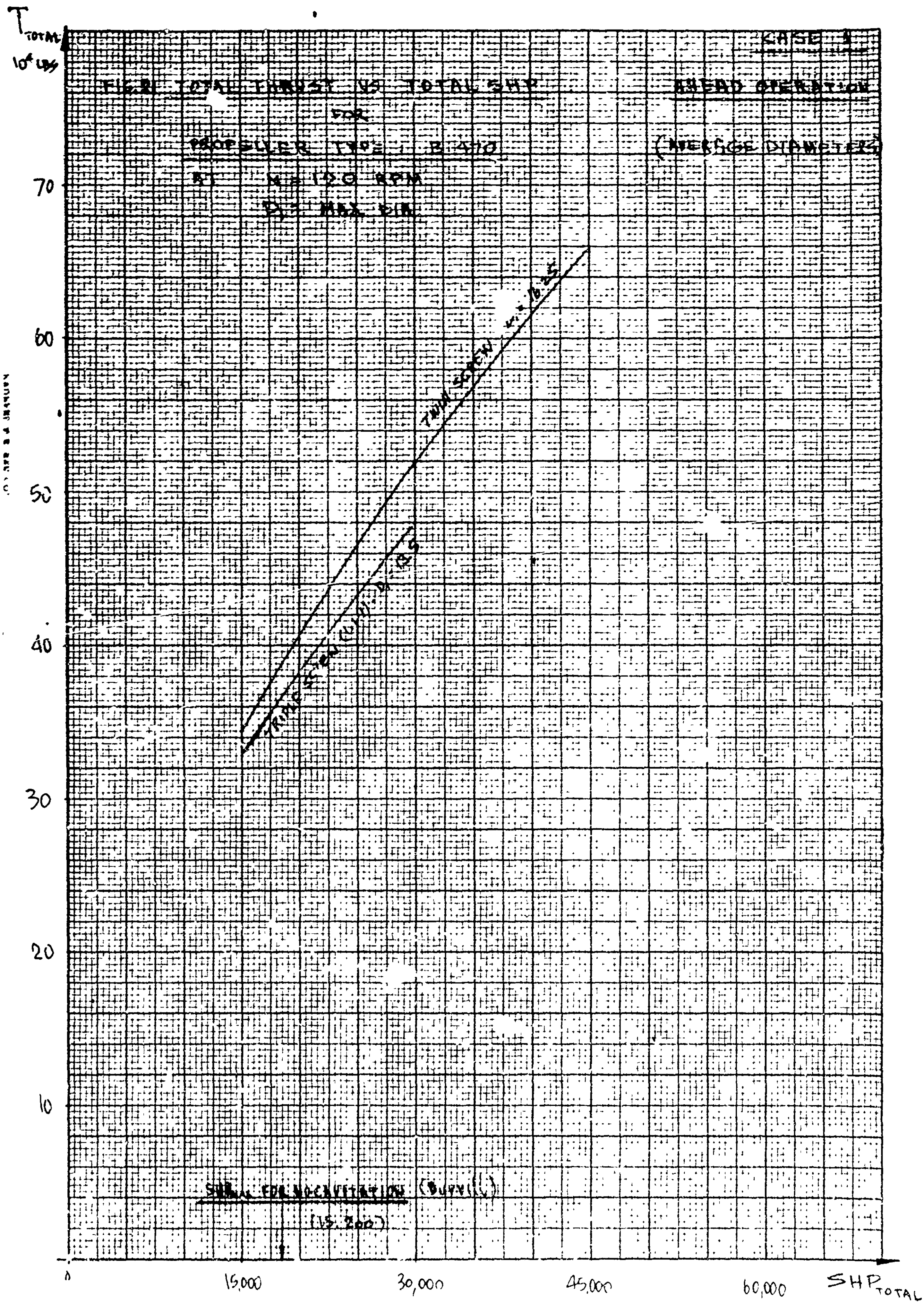

CASE I
PROP. TYPE
B 3.50
FIG 18 TOTAL THRUST VS TOTAL SHP
FOR TWIN SCREW
FOR MAX DIA
AVERAGE DIAMETERS
AT N = 120 RPM
T 10^4 lbs (TOTAL)
90
80
70
60
50
40
30
20
10
0
TWIN SCREW
NOTE: ALL OTHER ARRANGEMENTS OF TRIPLE SCREW AND REDUCED DIAMETERS ARE OUT OF THE CAPABILITY OF THIS PROPELLER
0
15,000
30,000
45,000
60,000
SHP (TOTAL)



T 10³ lbs
(TOTAL)
CASE I
PROP. TYPE
B-3.65
FIG. 19 TOTAL THRUST VS TOTAL SHP
FOR 1. TWIN SCREW
2. TRIPLE SCREW (1:1:1)
(1:2:1)
FOR D₁ = MAX DIA
AT N = 120 RPM
AHEAD OPERATION - AVERAGE DIAMETERS
TWIN SCREW
D₁ = 16.25'
TRIPLE SCREW (1:1:1)
D₁ = 13.5'
TRIPLE SCREW (1:2:1)
D₁ = 11.81'
90
80
70
60
50
40
30
20
10
0
15000
30000
45000
60000
SHP
TOTAL

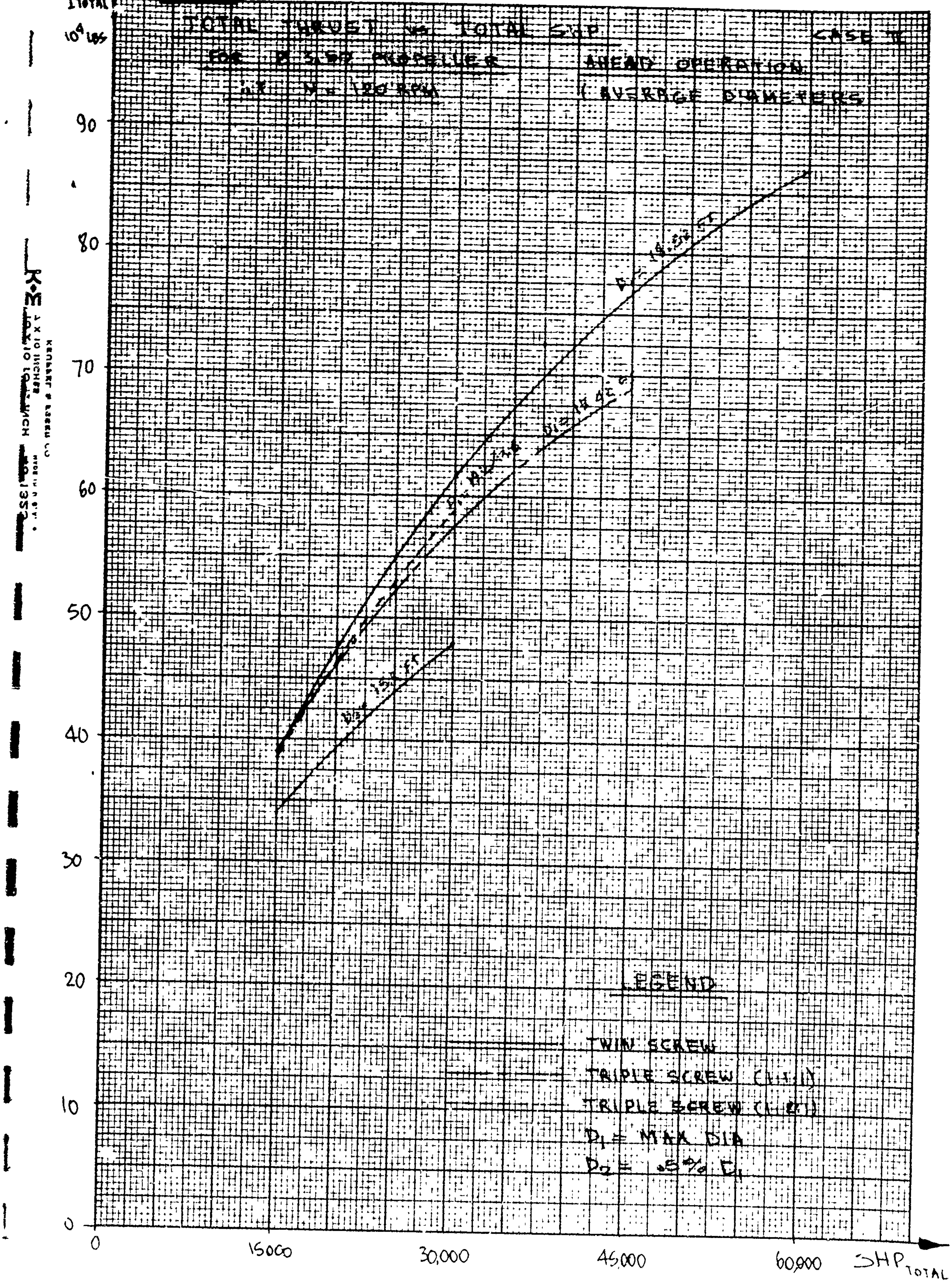


CASE I
TOTAL SHP
FOR 1. TWIN SCREW
2 TRIPLE SCREW
AT N = 120 RPM.
AVERAGE DIAMETERS
(TOTAL)
90
80
70
60
50
40
30
20
10
TWIN SCREW
TRIPLE SCREW
15,000

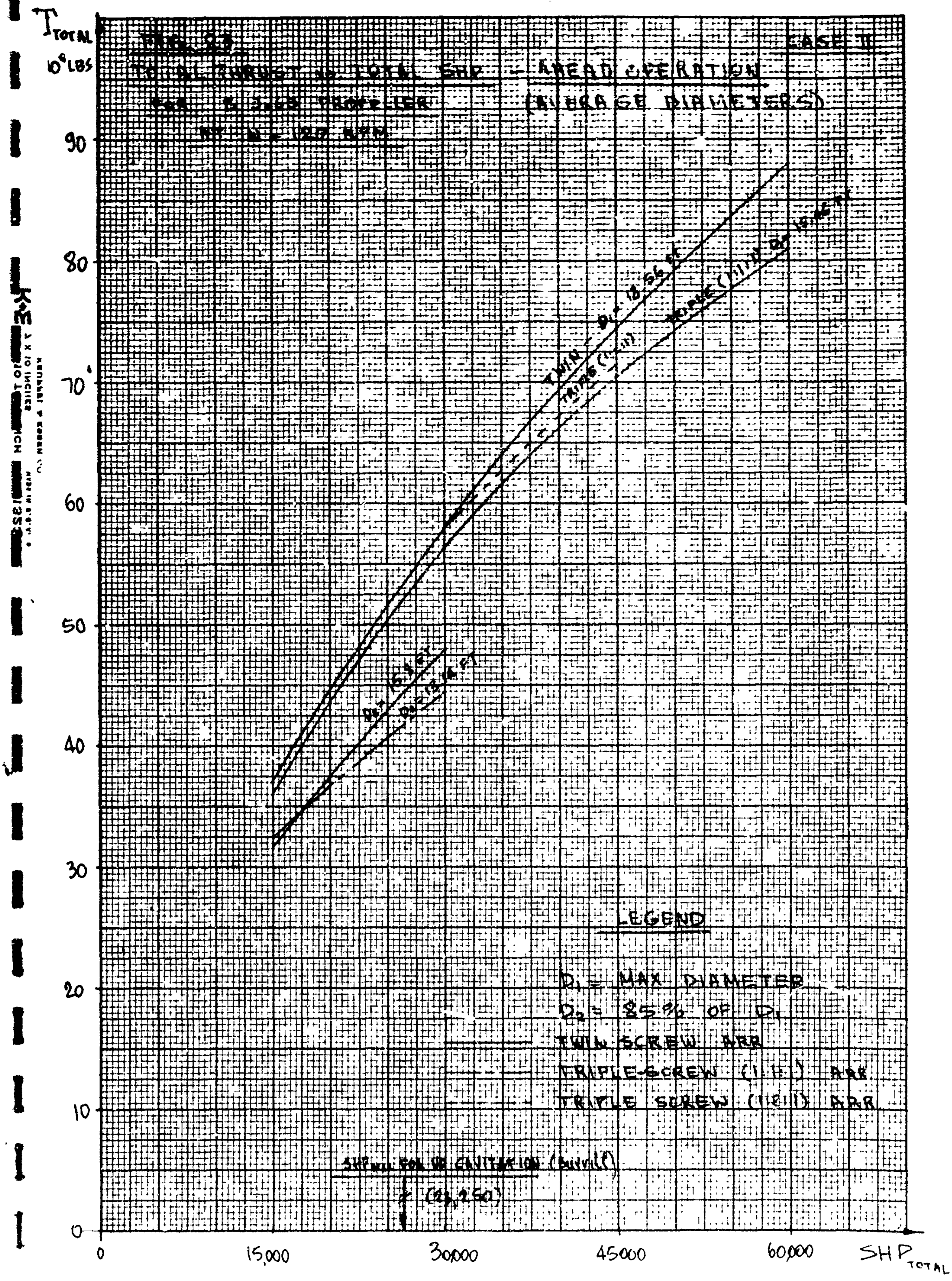


TOTAL THRUST VS TOTAL SHP
FOR
N = 120 RPM
MAX DIA
CASE
TWIN SCREW
FOR NO CAVITATION (BURRILL)
(15,200)
70
60
50
40
30
20
10
0
15,000
30,000
45,000
60,000
SHP TOTAL

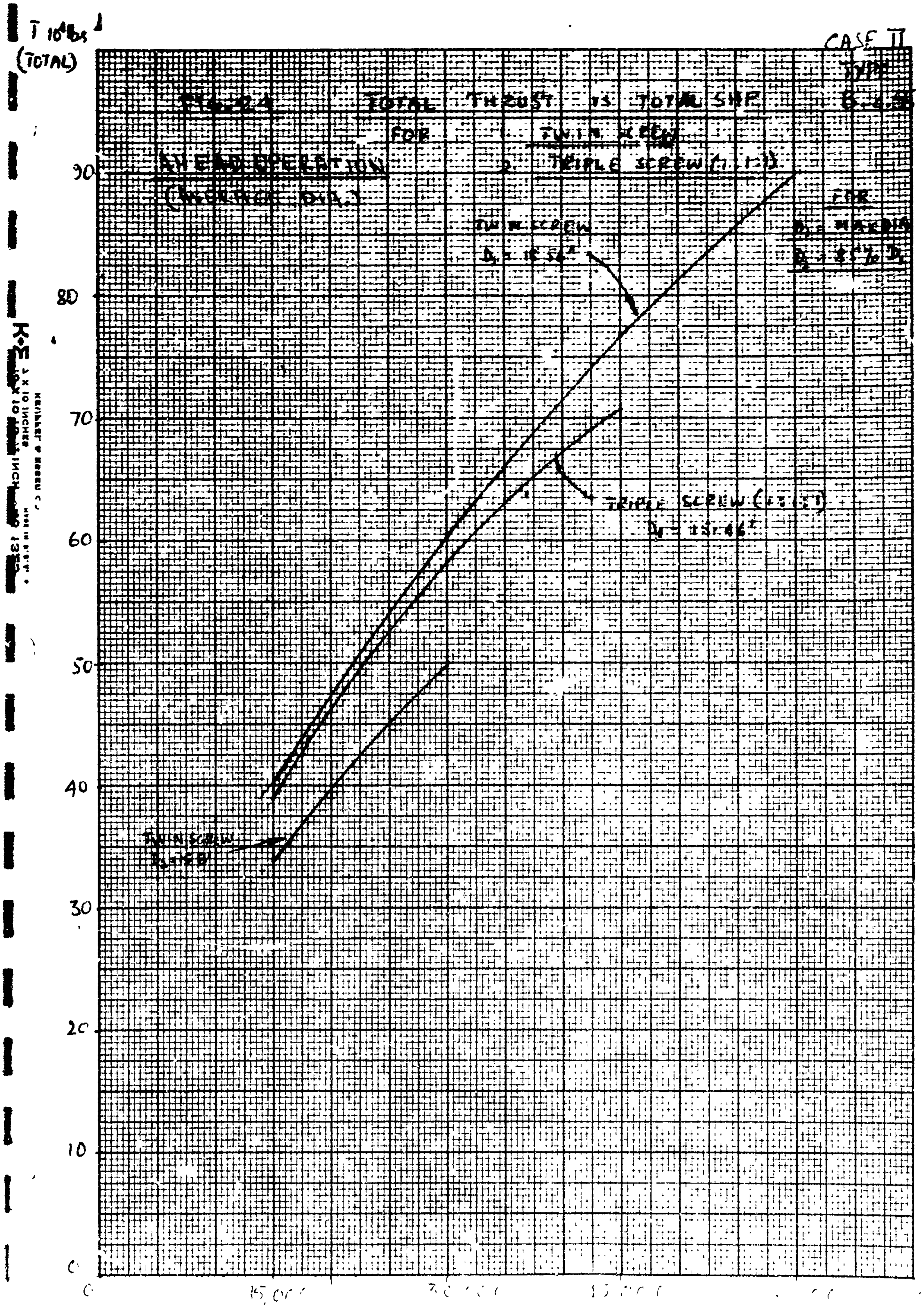
FIG. 22

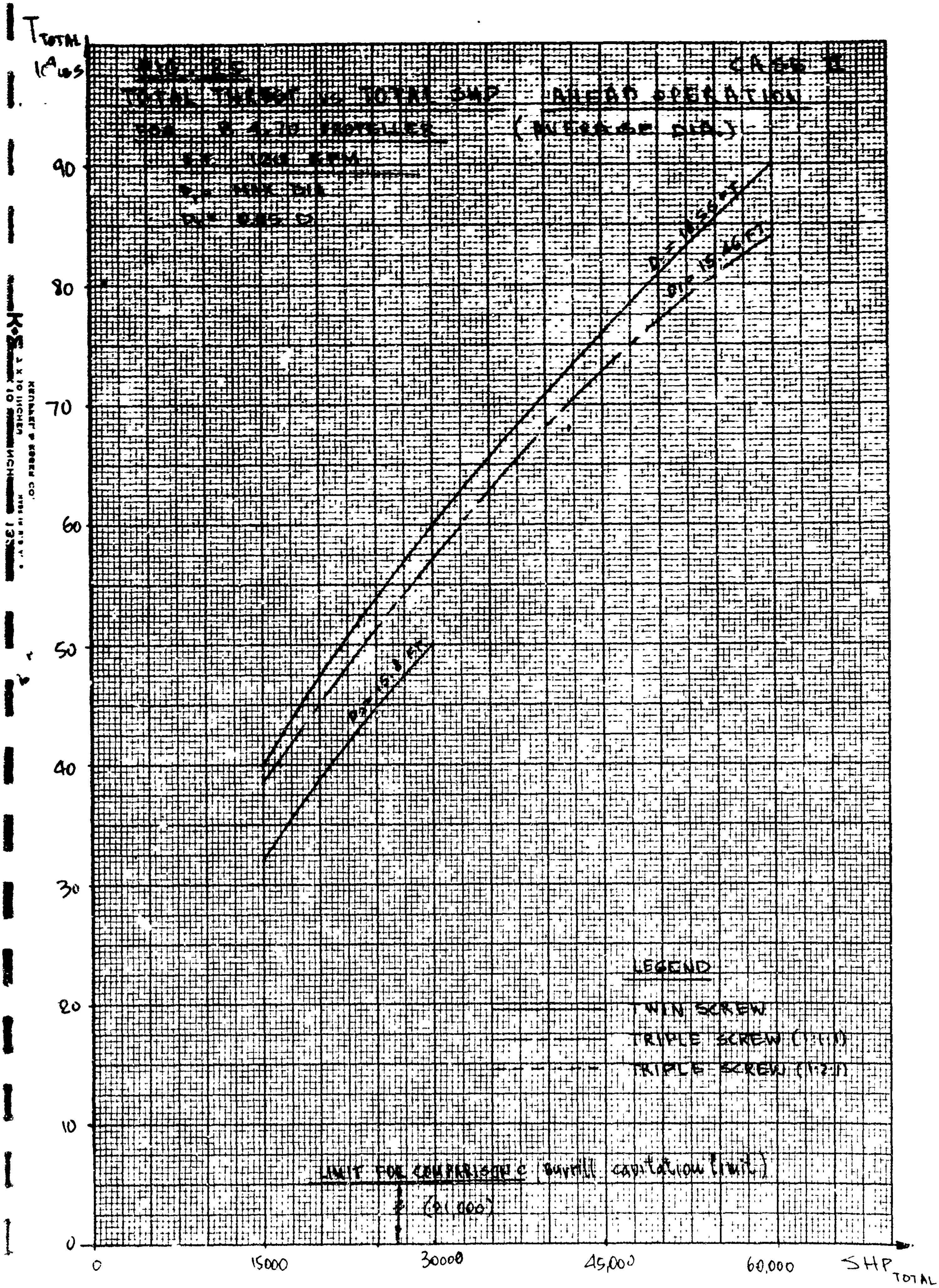


T_{TOTAL}
10^4 LBS
TOTAL THRUST vs TOTAL SHP
CASE II
FOR B SERIES PROPELLER
AHEAD OPERATION
AT N = 120 RPM
(AVERAGE DIAMETERS)
90
80
70
60
50
40
30
20
10
0
0
15000
30,000
45,000
60,000
SHP_{TOTAL}
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D_1 = MAX DIA
D_2 = .85% D_1

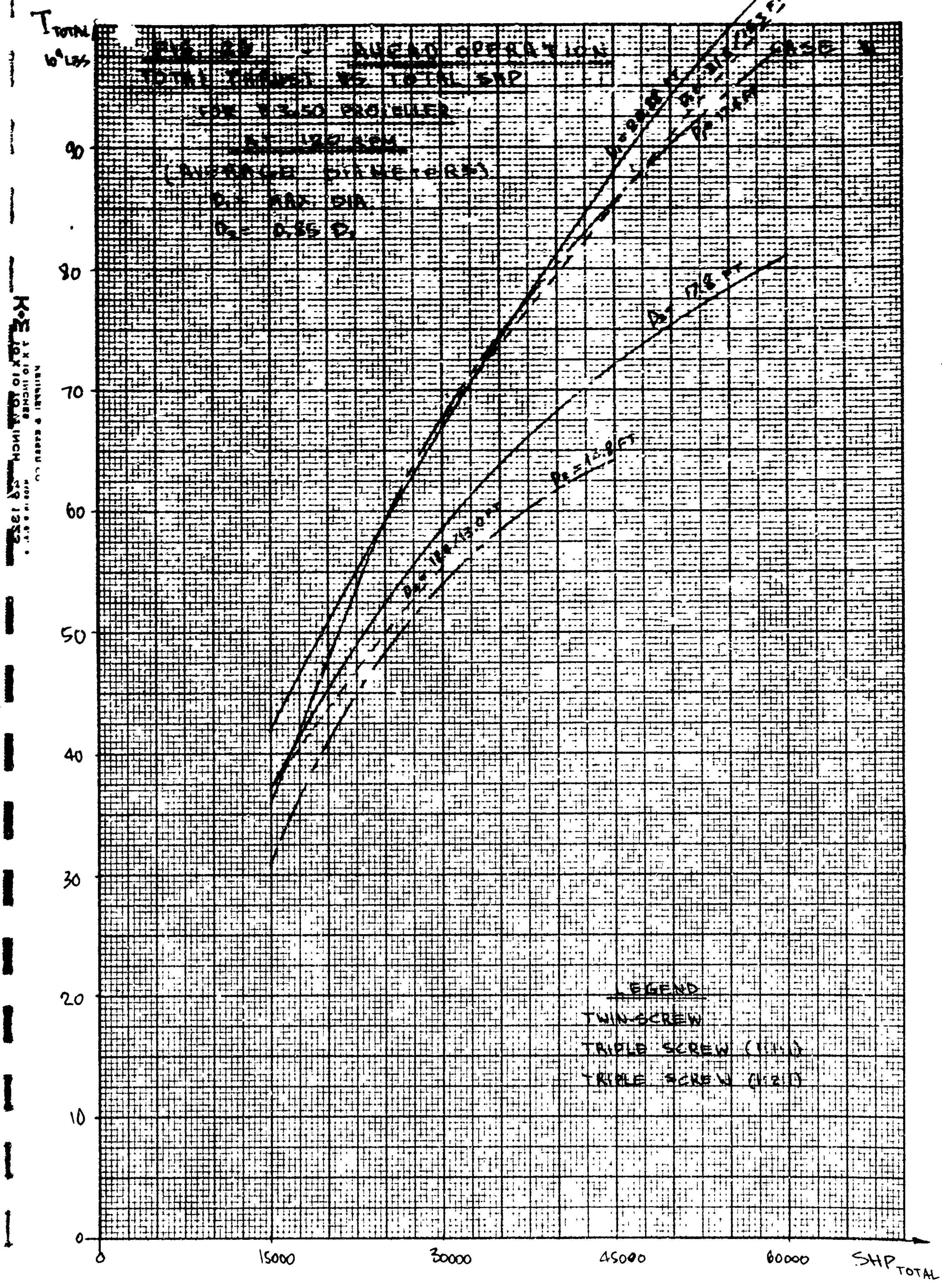


CASE II
AHEAD OPERATION
(AVERAGE DIAMETERS)
T_{TOTAL} 10^3 LBS
SHP_{TOTAL}
0
10
20
30
40
50
60
70
80
90
15,000
30,000
45000
60,000
LEGEND
D_1 = MAX DIAMETER
D_2 = 85% OF D_1
TWIN SCREW ARR
TRIPLE-SCREW (1:1:1) ARR
TRIPLE SCREW (1:2:1) ARR
TWIN

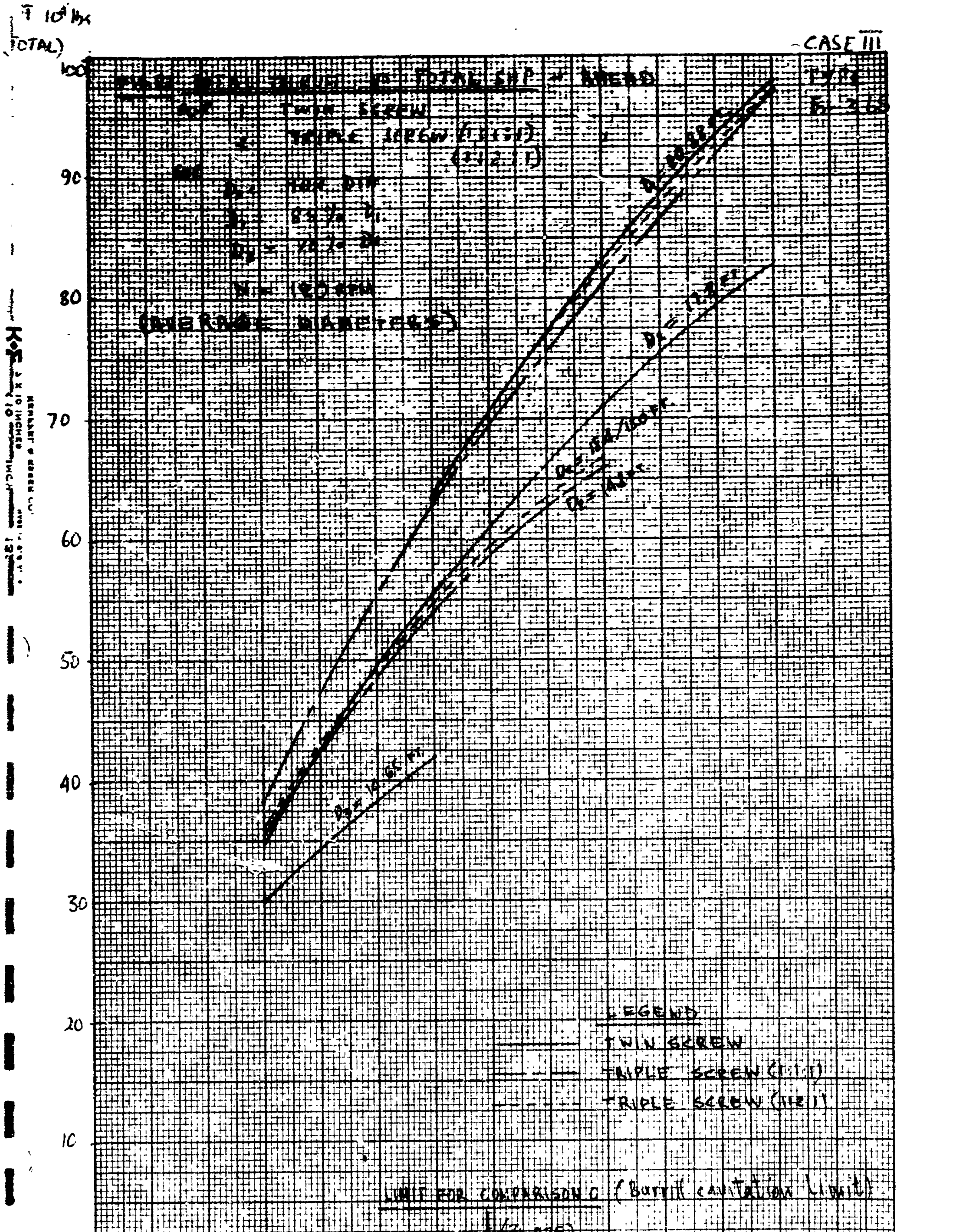

T 10^4 lbs
(TOTAL)
CASE II
TOTAL THRUST VS TOTAL SHP
FOR
TWIN SCREW
TRIPLE SCREW
AHEAD OPERATION
TWIN SCREW
FOR
TRIPLE SCREW
TWIN SCREW
90
80
70
60
50
40
30
20
10
0

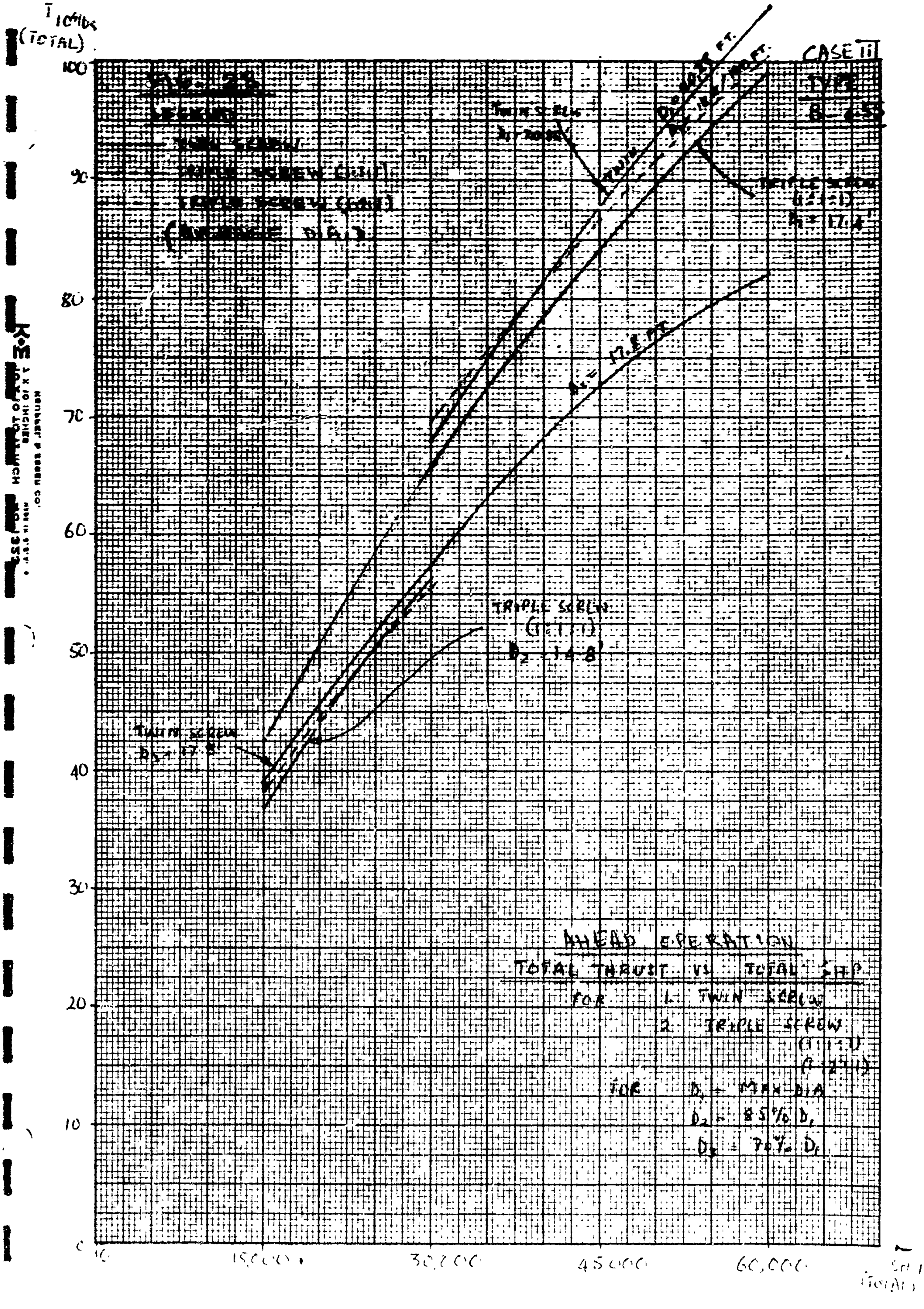


TOTAL THRUST vs TOTAL SHP
AHEAD OPERATION
(AVERAGE DIA)
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
LIMIT FOR COMPARISON (Burrill cavitation limit)
(21,000)
T TOTAL
10^4 lbs
90
80
70
60
50
40
30
20
10
0
0
15000
30000
45,000
60,000
SHP TOTAL

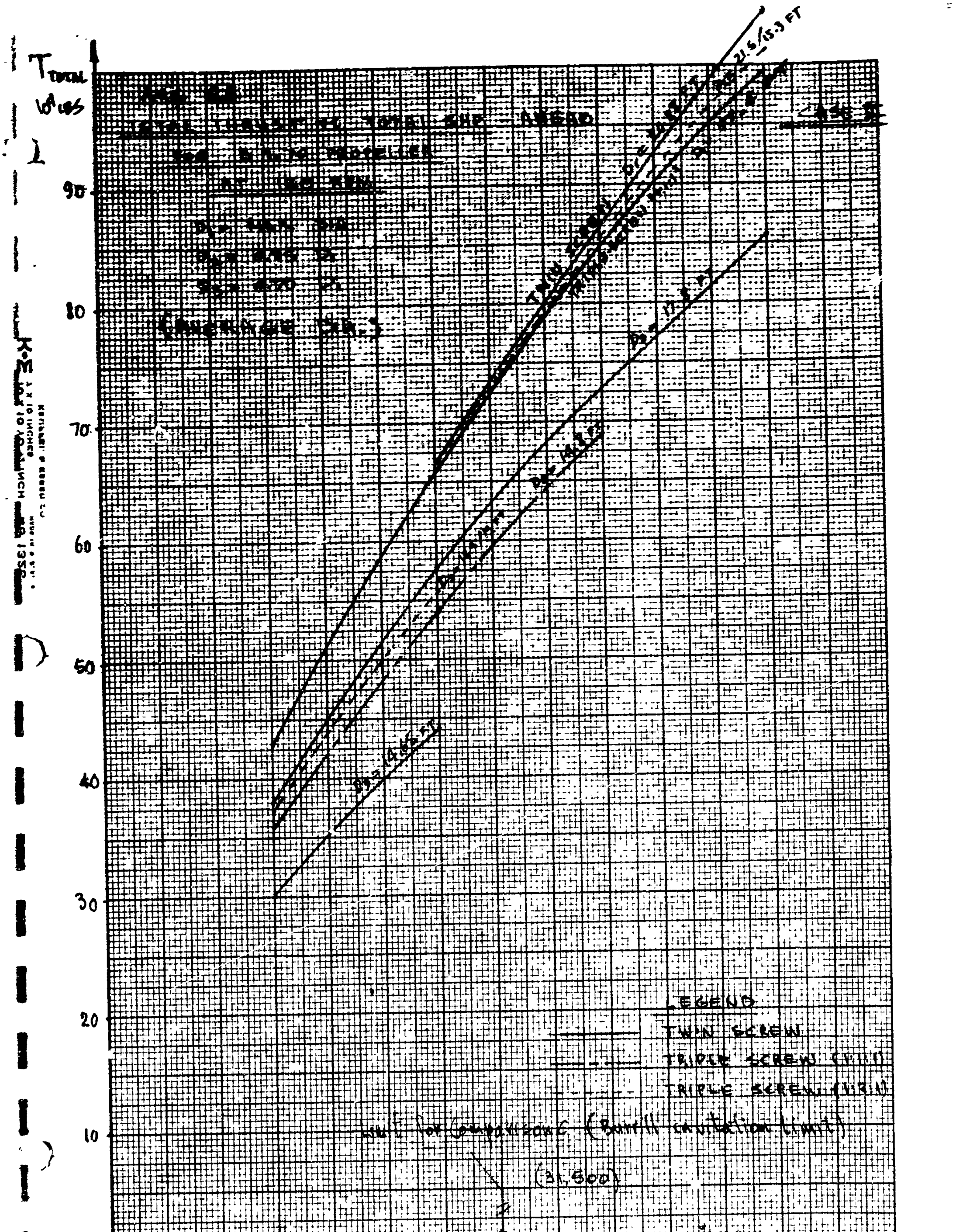

AHEAD OPERATION
TOTAL THRUST VS TOTAL SHP
(AVERAGE DIAMETERS)
LEGEND
TWIN-SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
T TOTAL
0
10
20
30
40
50
60
70
80
90
15000
30000
45000
60000
SHP TOTAL

CASE III

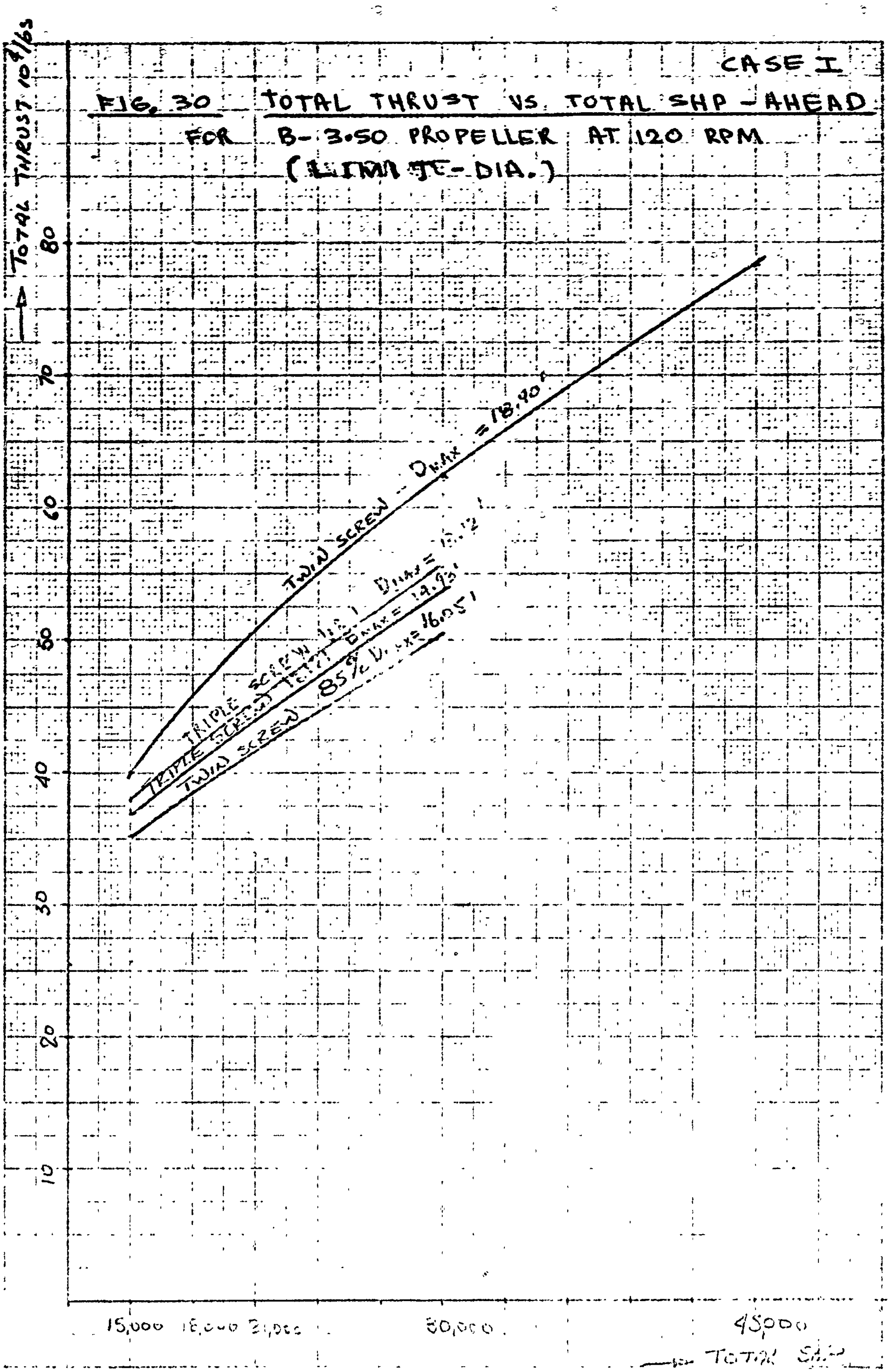

TWIN SCREW
(AVERAGE DIAMETERS)
100
90
80
70
60
50
40
30
20
10
0
15,000
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
LIMIT FOR COMPARISON C (Burrill cavitation limit)

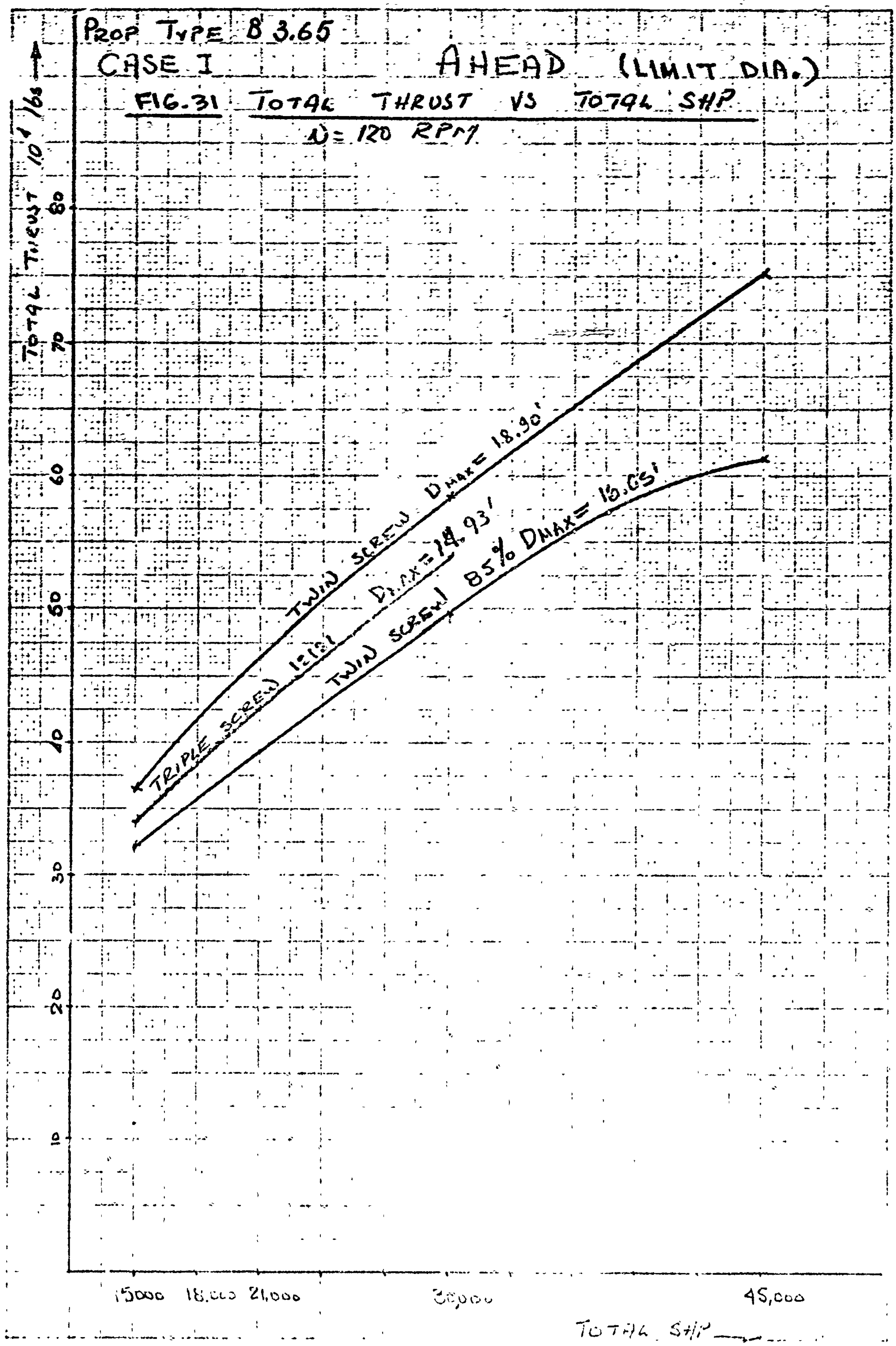


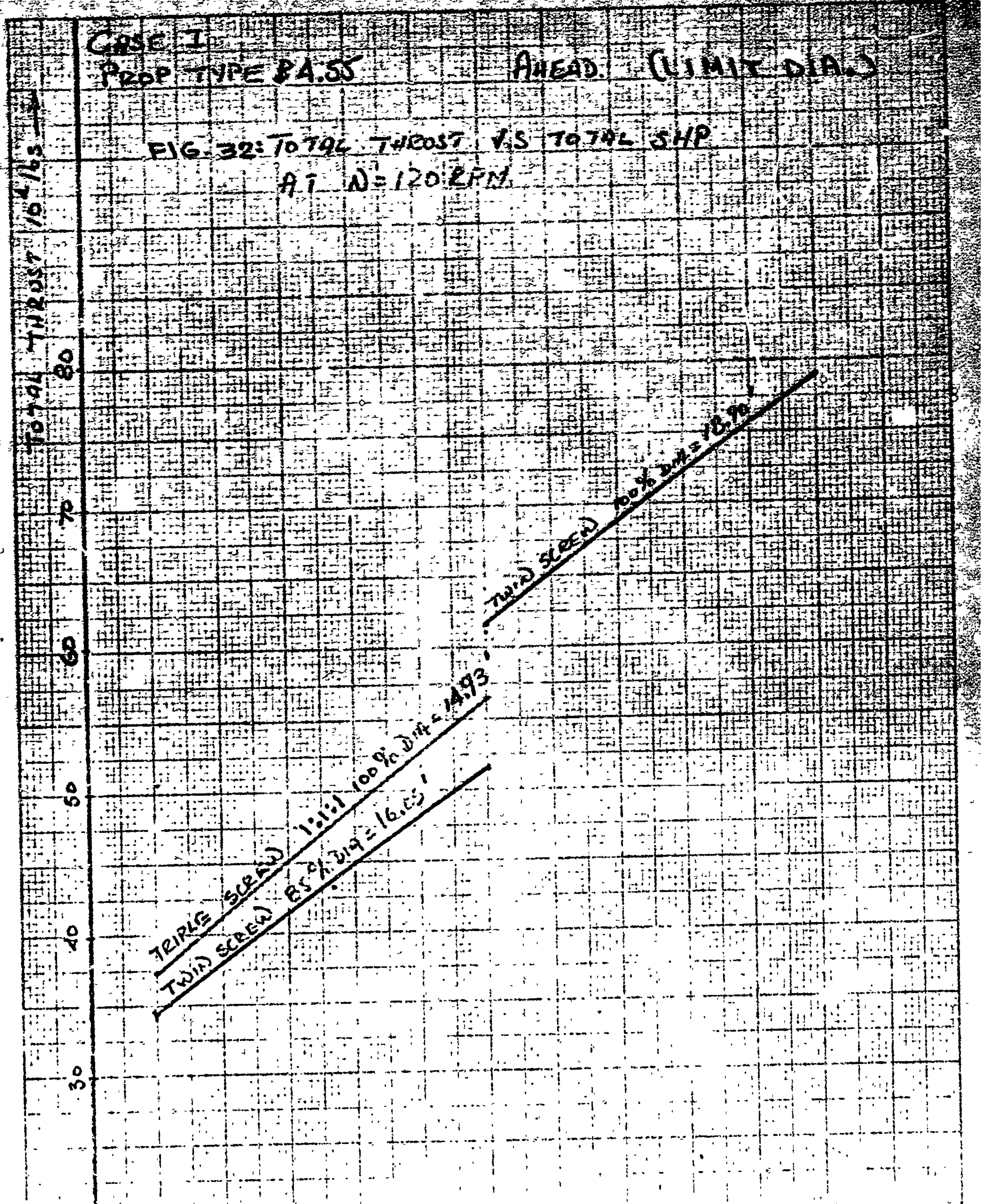
CASE III
TRIPLE SCREW (1:1:1) D_2 = 14.8'
TWIN SCREW D_3 = 17.8'
AHEAD OPERATION
TOTAL THRUST VS TOTAL SHP
FOR 1. TWIN SCREW
2. TRIPLE SCREW (1:1:1) (1:2:1)
FOR D_1 = MAX DIA
D_2 = 85% D_1
D_3 = 70% D_1
T 10^4 lbs (TOTAL)
100
90
80
70
60
50
40
30
20
10
15,000
30,000
45,000
60,000
SHP (TOTAL)



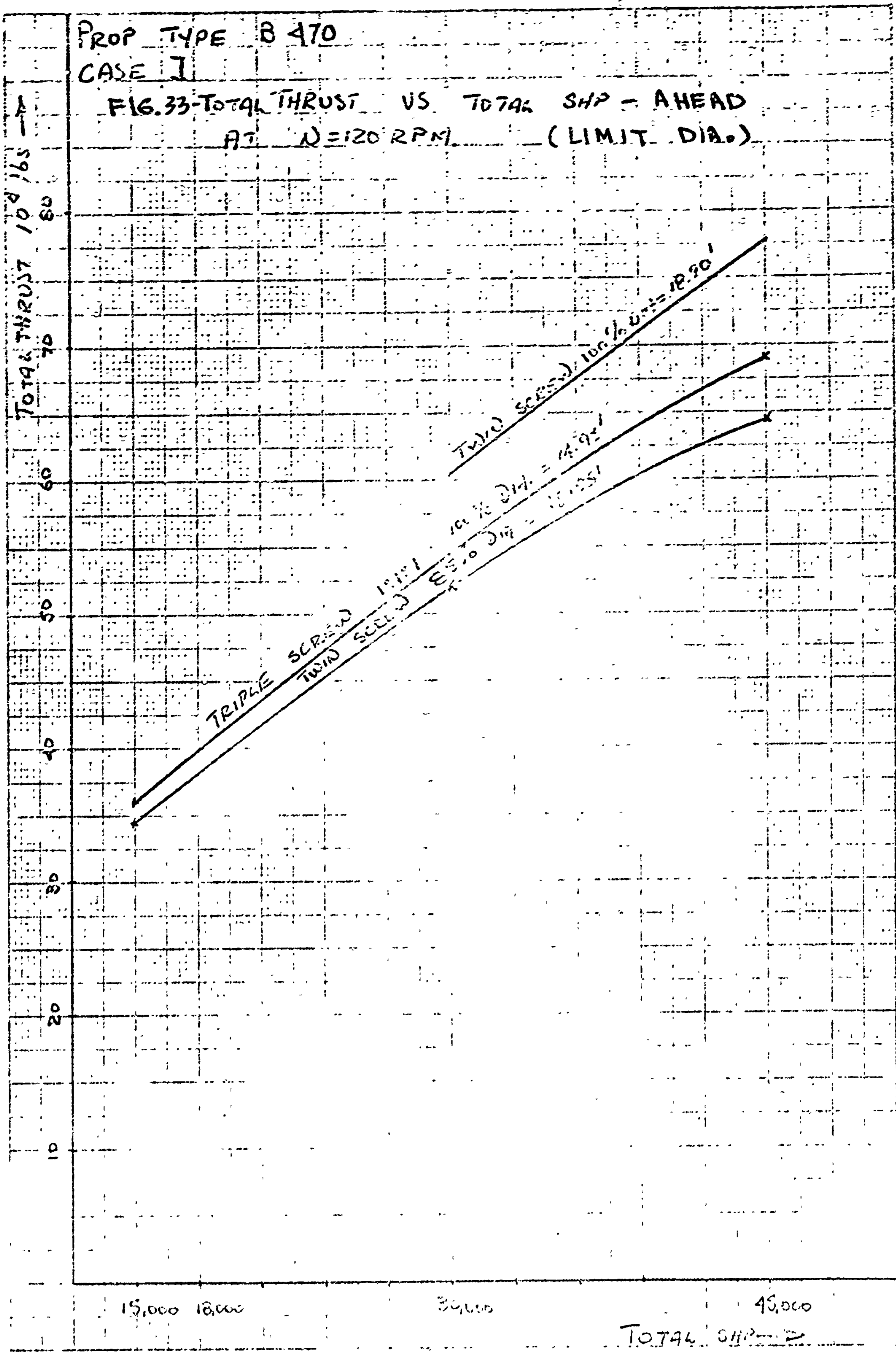
T_{TOTAL}
10^3 LBS
90
80
70
60
50
40
30
20
10
0
15,000
30000
45000
60000
SHP_{TOTAL}
TWIN SCREW
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW
(31,500)

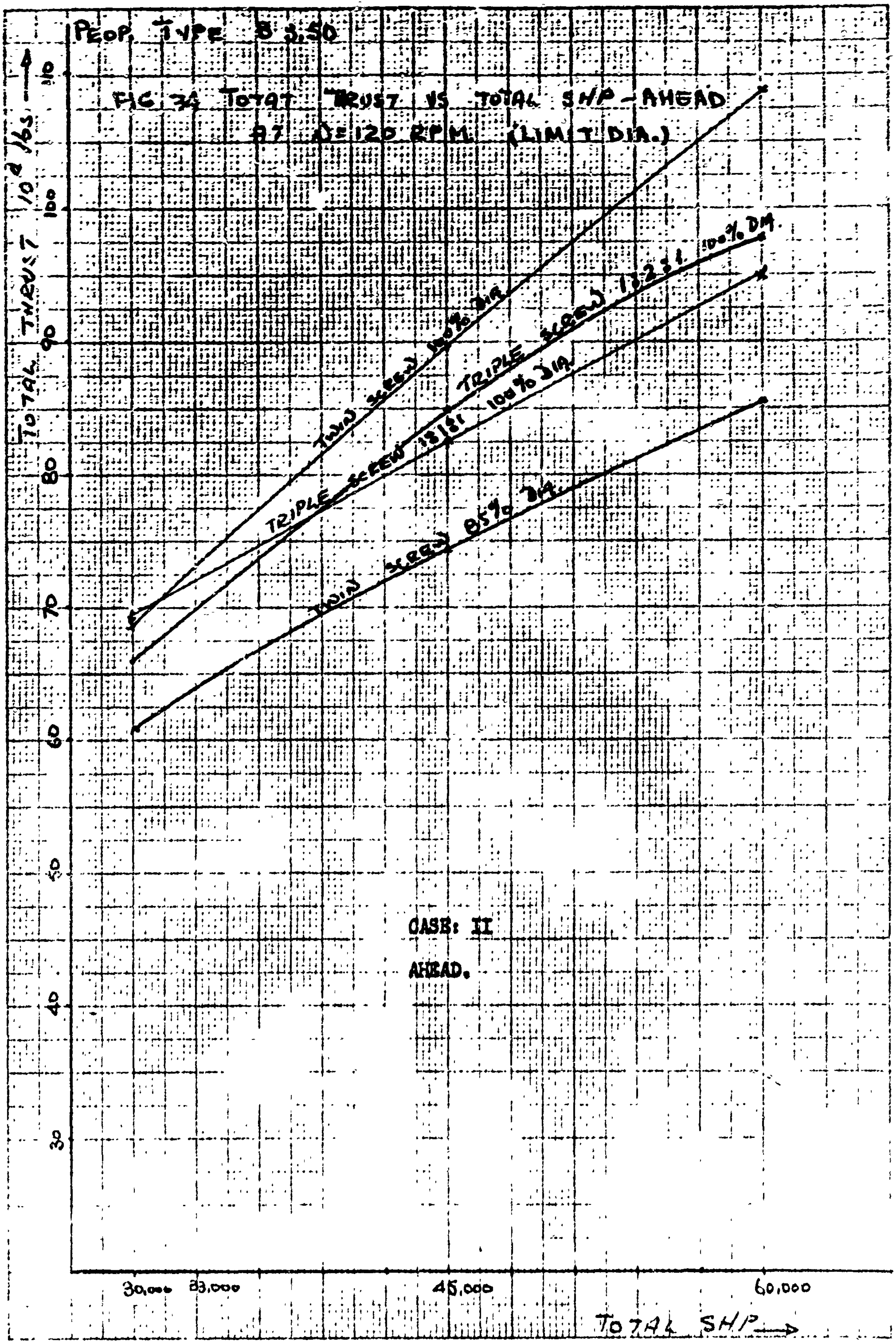

CASE I
FIG. 30 TOTAL THRUST VS. TOTAL SHP - AHEAD
FOR B-3.50 PROPELLER AT 120 RPM
DIA.)
TOTAL THRUST 10³ lbs
80
70
60
50
40
30
20
10
TWIN SCREW - DMAX = 18.90'
TRIPLE SCREW
TRIPLE SCREW
TWIN SCREW 85% DMAX = 16.05'
15,000
18,000
21,000
30,000
45,000
TOTAL SHP


PROP TYPE B 3.65
CASE I
AHEAD (LIMIT DIA.)
FIG. 31 TOTAL THRUST VS TOTAL SHP
N = 120 RPM
TOTAL THRUST 10^4 lbs
TWIN SCREW D_{MAX} = 18.90'
TRIPLE SCREW 1:1:1 D_{MAX} = 14.93'
TWIN SCREW 85% D_{MAX} = 16.05'
80
70
60
50
40
30
20
10
15000
18,000
21,000
30,000
45,000
TOTAL SHP



CASE I
PROP TYPE B4.55
AHEAD (LIMIT DIA.)
FIG. 32: TOTAL THRUST VS TOTAL SHP
AT N=120 RPM.
TOTAL THRUST 10^4 lbs →
80
70
60
50
40
30
20
TRIPLE SCREW 1:1:1 100% DIA = 14.93
TWIN SCREW 85% DIA = 16.05'
TWIN SCREW 100% DIA = 18.90'
15,000
30,000
45,0..
TOTAL SHP →


PROP TYPE B 470
CASE I
FIG.33-TOTAL THRUST VS TOTAL SHP - AHEAD
AT N=120 RPM (LIMIT DIA.)
TOTAL THRUST 10^3 lbs
TWIN SCREW 100% DIA = 18.90'
TRIPLE SCREW 100% DIA = 14.92'
TWIN SCREW 85% DIA = 16.05'
80
70
60
50
40
30
20
10
15,000
18,000
30,000
45,000
TOTAL SHP


PROP. TYPE B 3.50
FIG 34 TOTAL THRUST VS TOTAL SHP - AHEAD
AT N=120 RPM. (LIMIT DIA.)
TOTAL THRUST 10^3 lbs
TWIN SCREW 100% DIA
TRIPLE SCREW 1:2:1 100% DIA.
TRIPLE SCREW 1:1:1 100% DIA
TWIN SCREW 85% DIA.
CASE: II
AHEAD.
30
40
50
60
70
80
90
100
110
30,000
33,000
45,000
60,000
TOTAL SHP

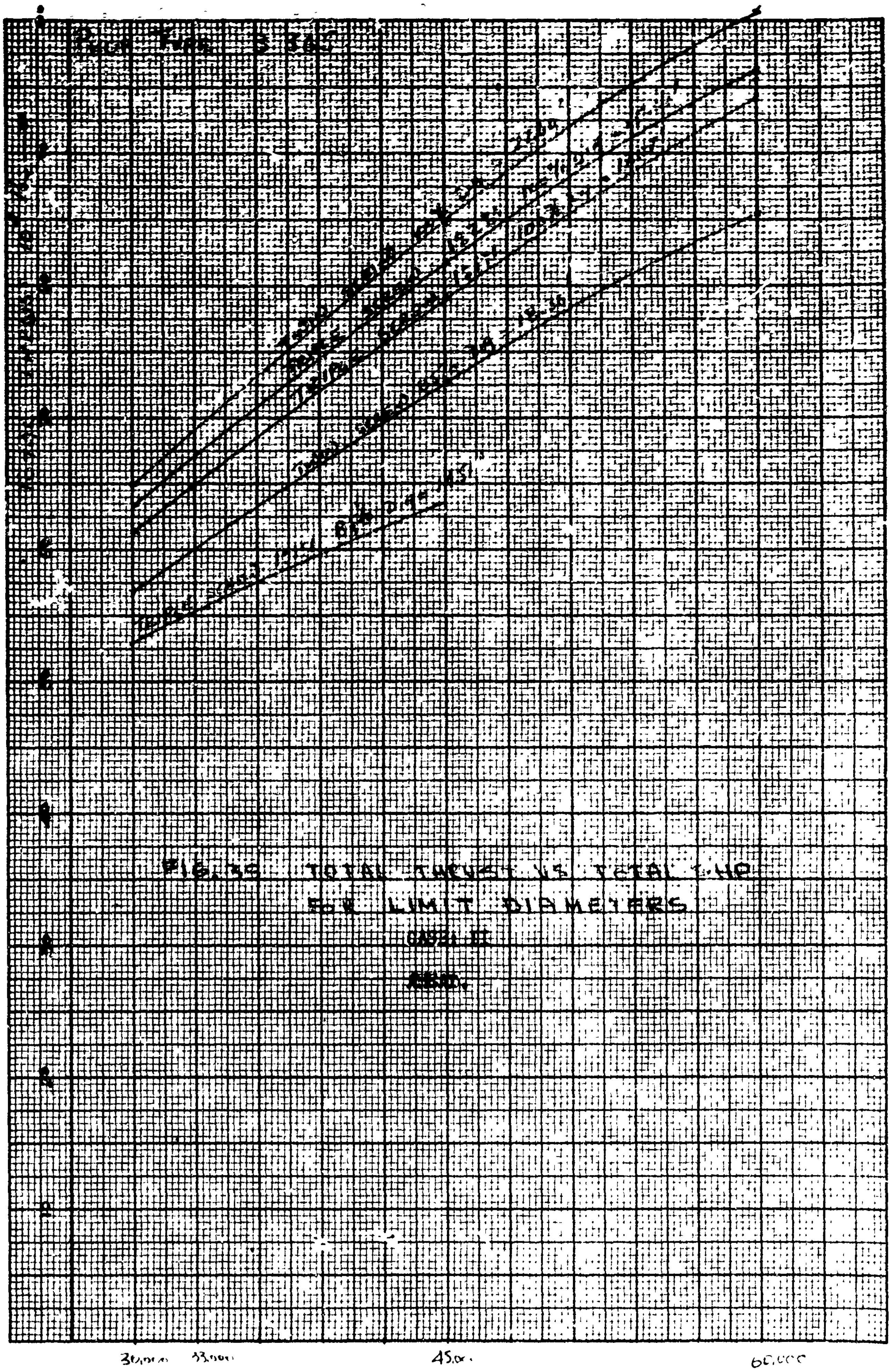


FIG. 35 TOTAL THRUST VS TOTAL SHP
FOR LIMIT DIAMETERS
CASE II

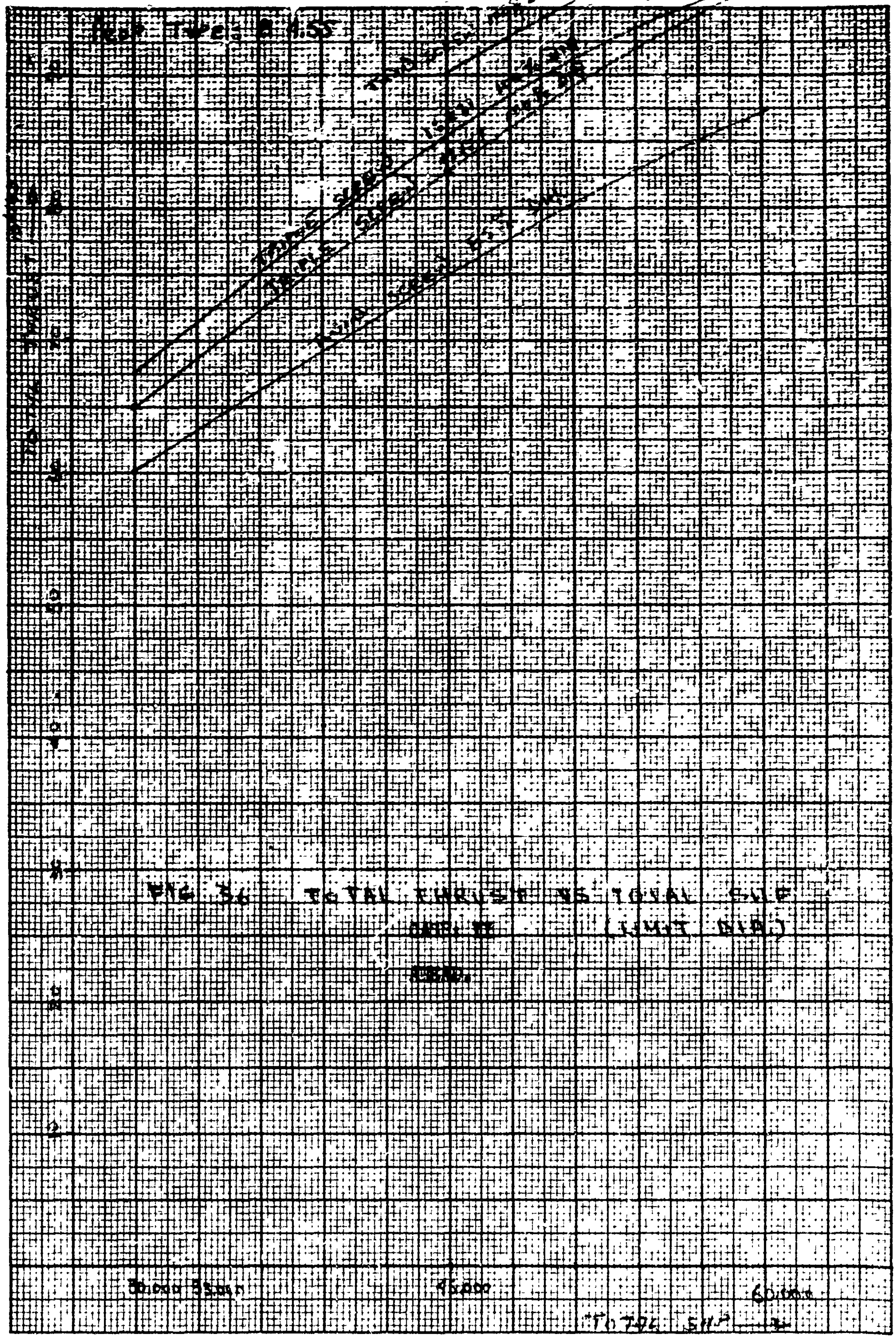


FIG. 36 TOTAL THRUST VS TOTAL SHP
[illegible] (L.M.T. DIA.)
[illegible]

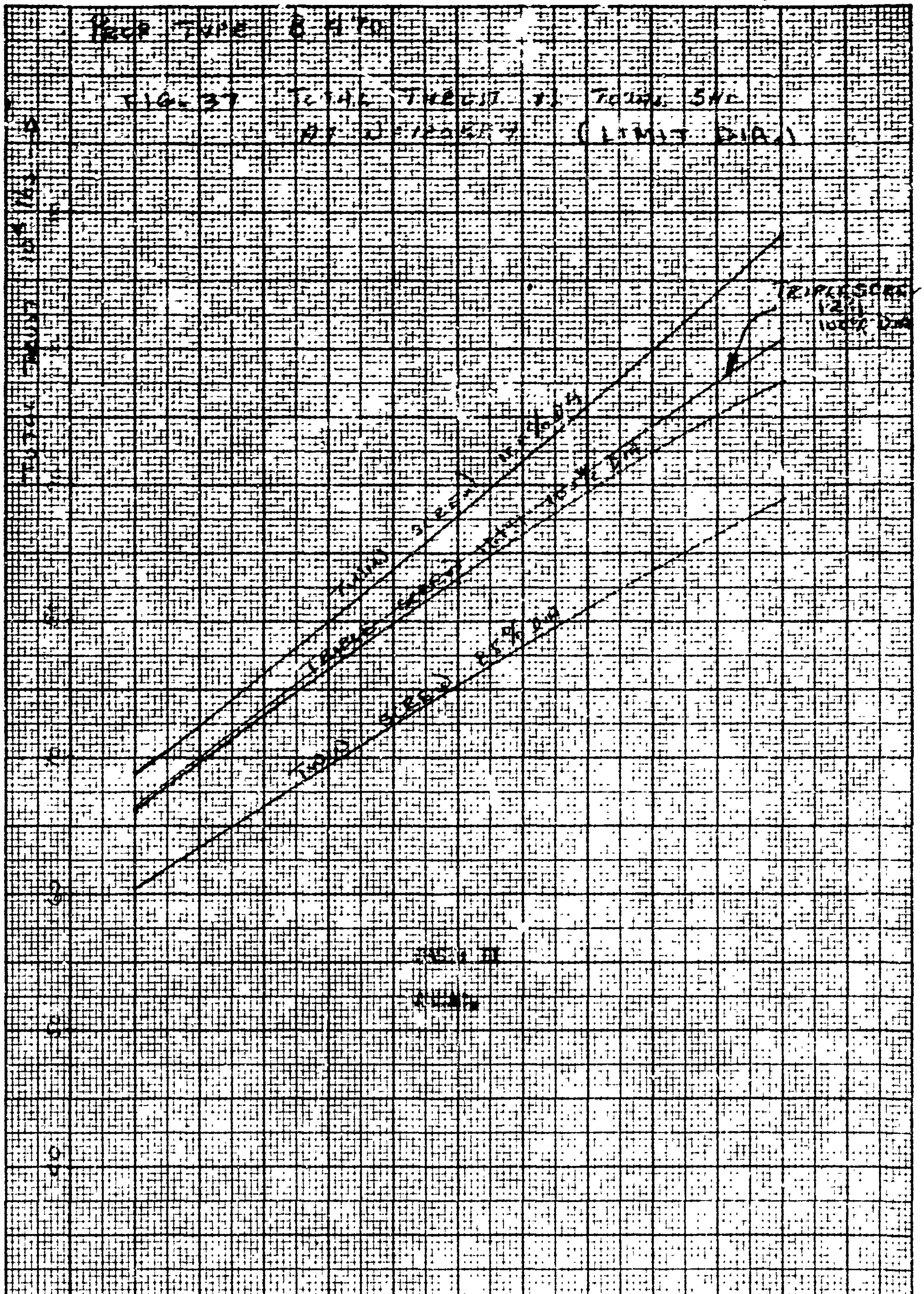
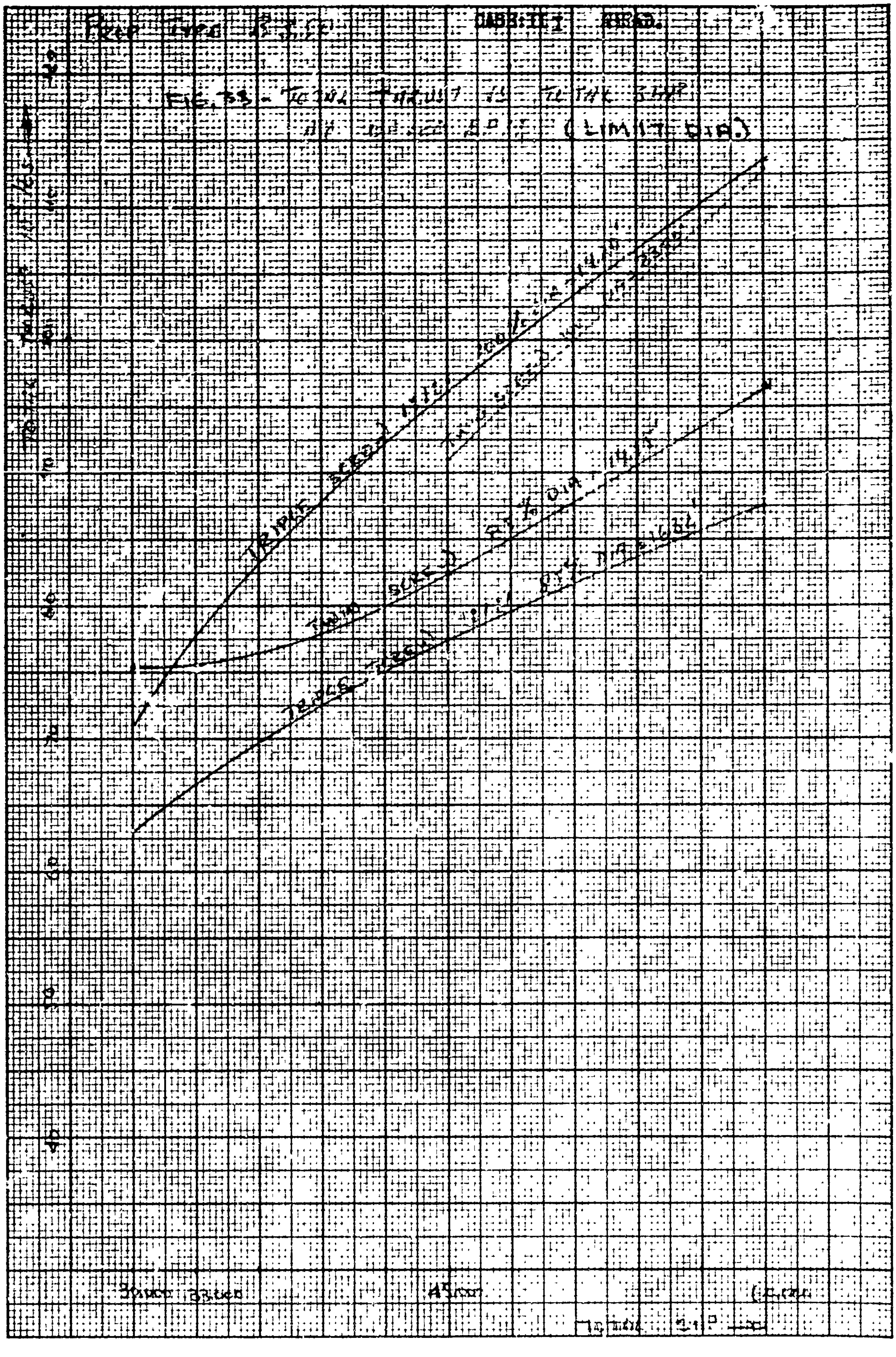
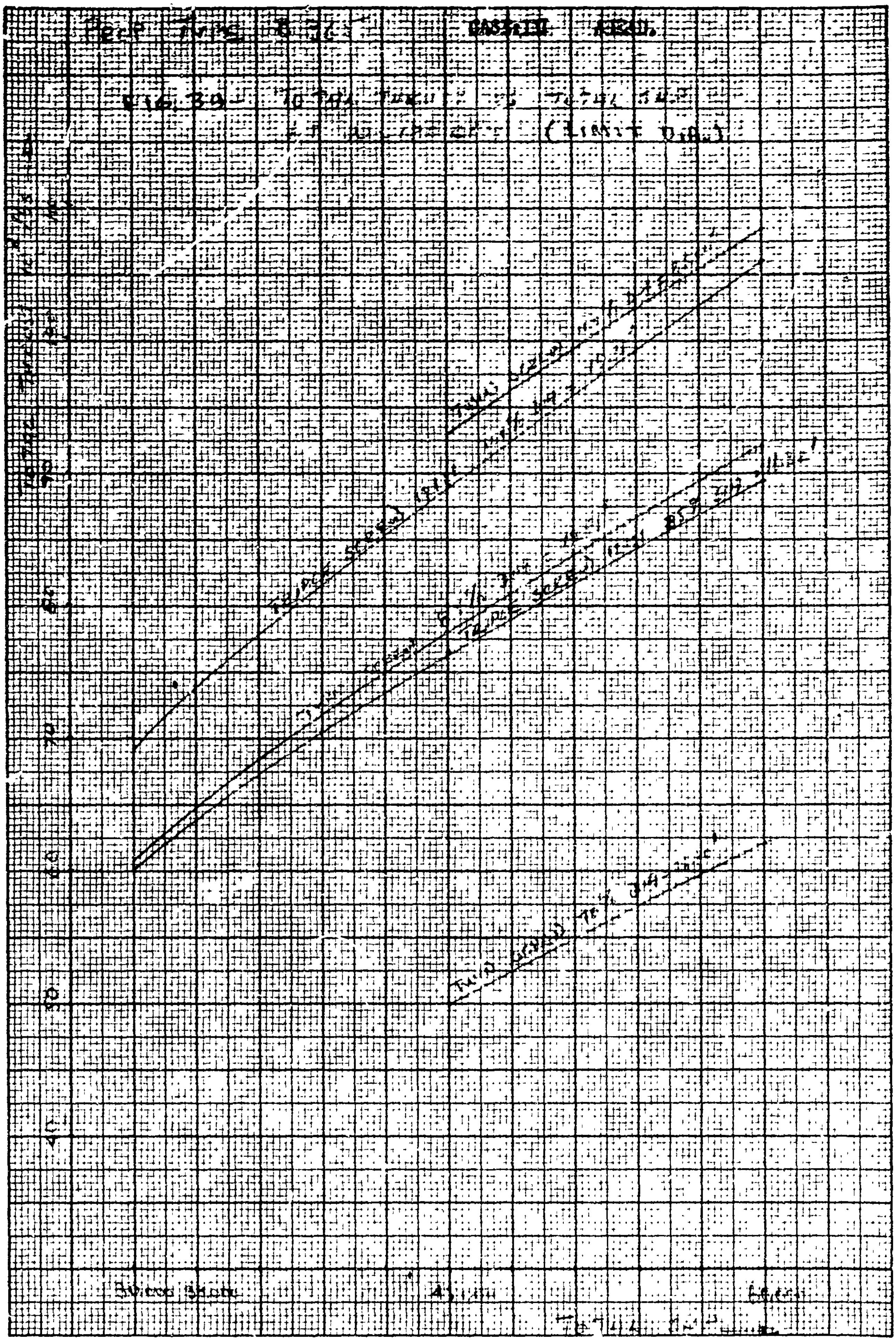


FIG. 37
(LIMIT DIA.)
TRIPLE SCREW
TWIN SCREW 85% DIA


(LIMIT DIA.)


(LIMIT D.R.)
TWIN SCREW
TRIPLE SCREW

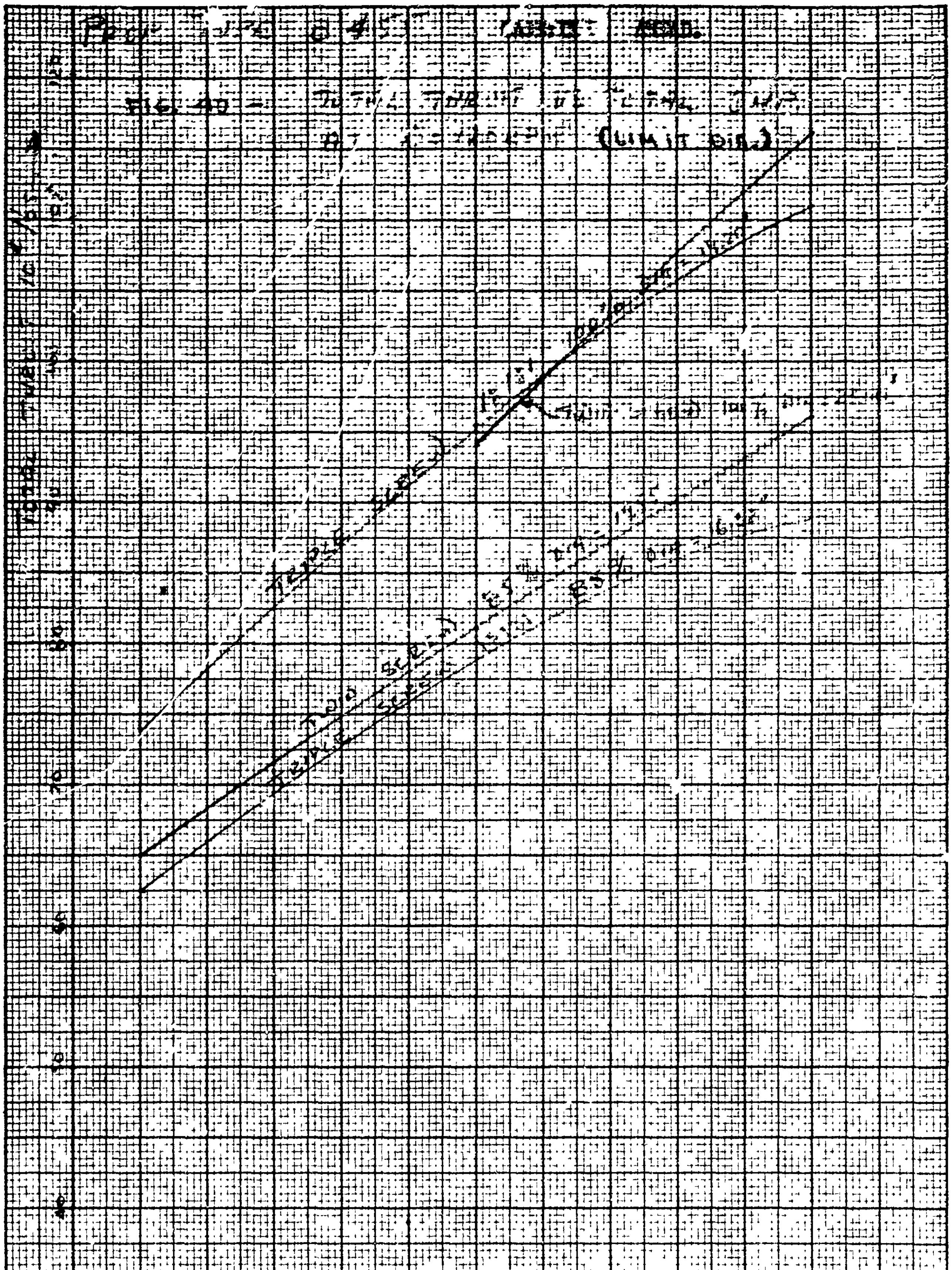
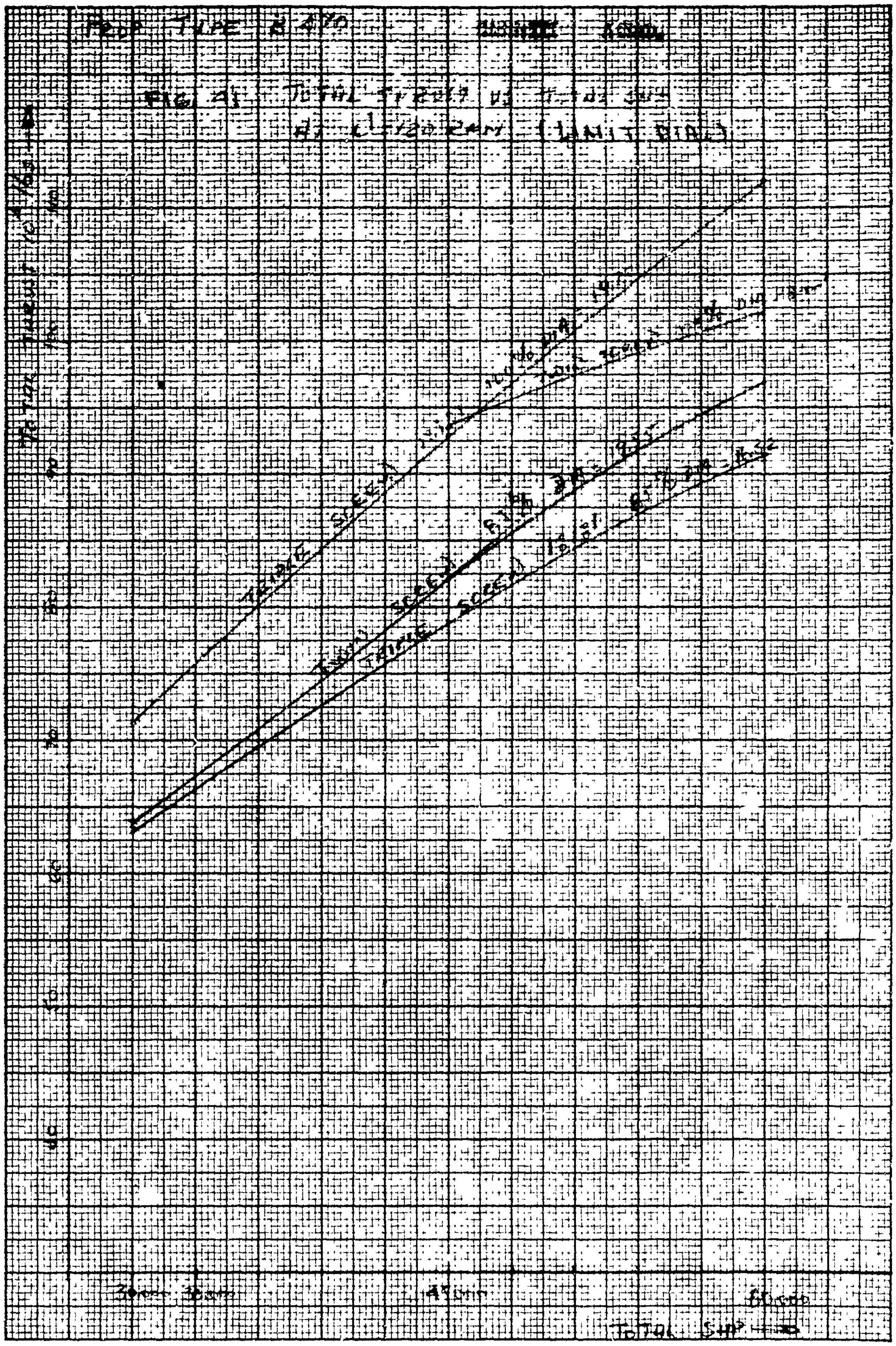
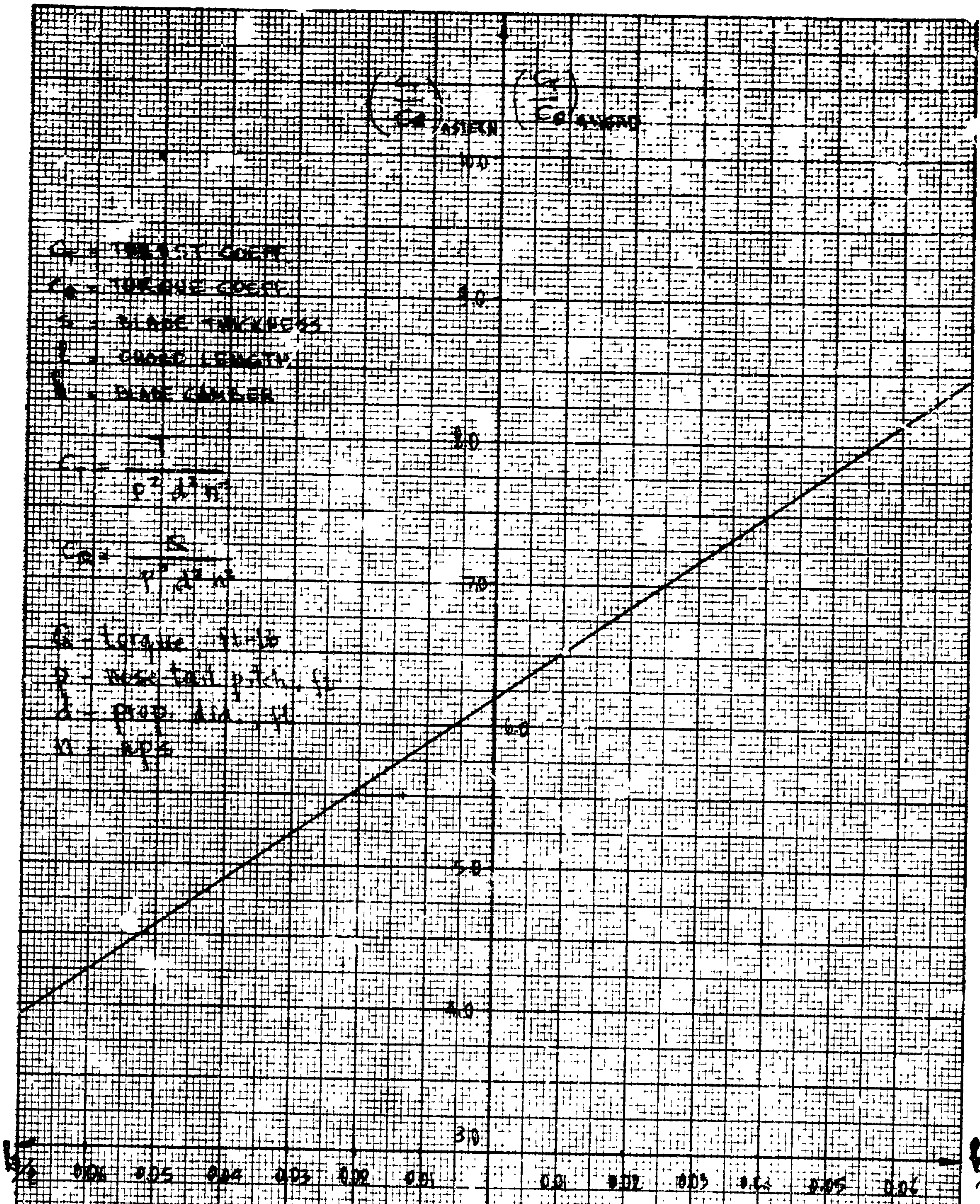


FIG. 49
TRIPLE SCREW
TWIN SCREW
TRIPLE SCREW
TOTAL SHP


PROP TYPE
FIG. 21 TOTAL THRUST VS TOTAL SHP
(LIMIT DIAL)
TOTAL THRUST
TRIPLE SCREW
TWIN SCREW
TRIPLE SCREW
60,000
TOTAL SHP

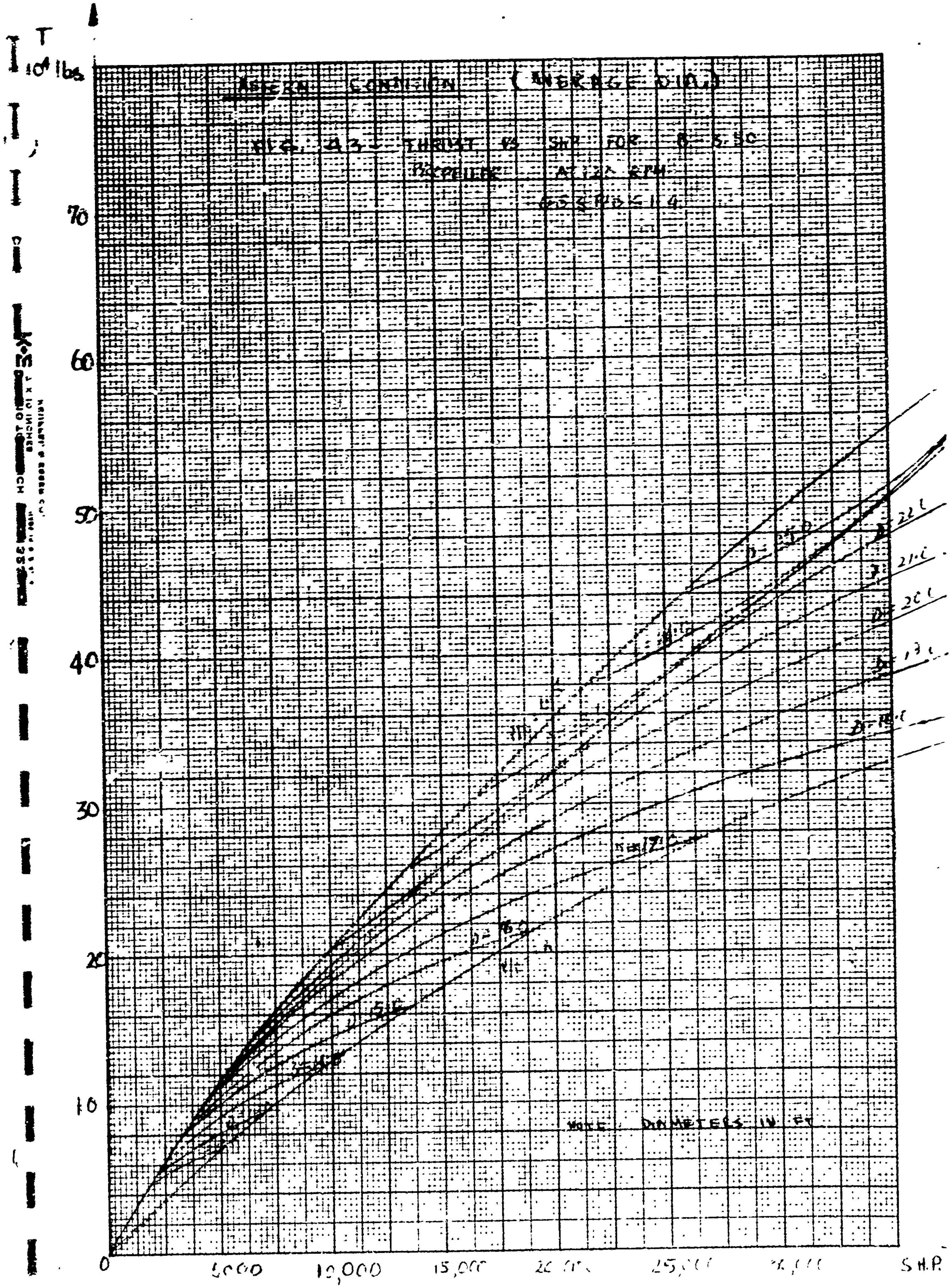


ASTERN ROTATION OF PROPELLER — AHEAD ROTATION OF PROPELLER

FIG. 42

THRUST TORQUE COEFFICIENT vs. BLADE CAMBER RATIO FOR AHEAD AND ASTERN PROPELLER ROTATION

Reference: Average of curves in Fig 21, SNAME Bulletin No. 3-5 "Guide to the selection of Backing power" edited by A.M. D'Archangelo


T
10^4 lbs
ASTERN CONDITION
THRUST
FOR
PROPELLER
RPM
70
60
50
40
30
20
10
0
5000
10,000
15,000
S.H.P.
DIAMETERS IN FT

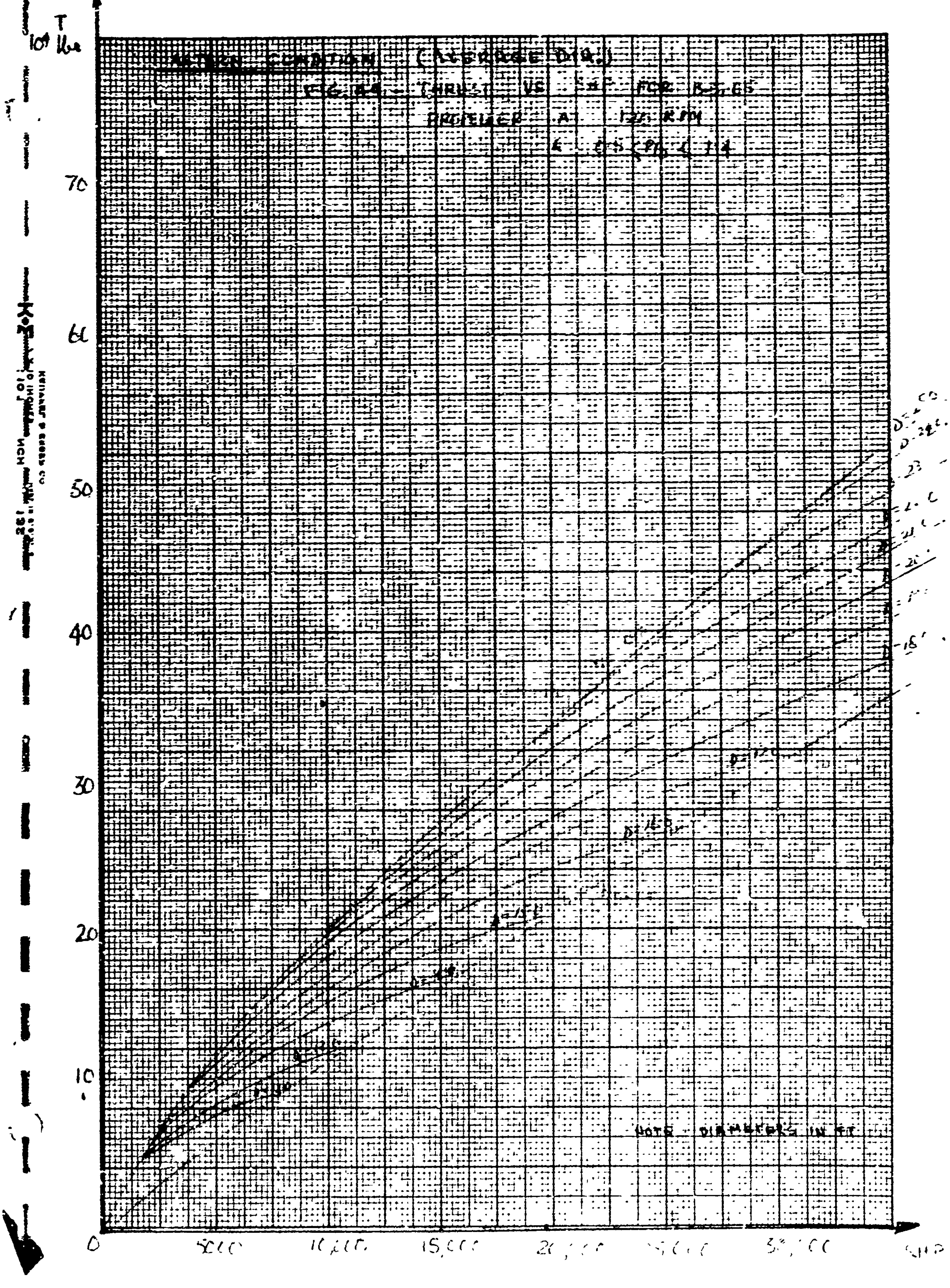
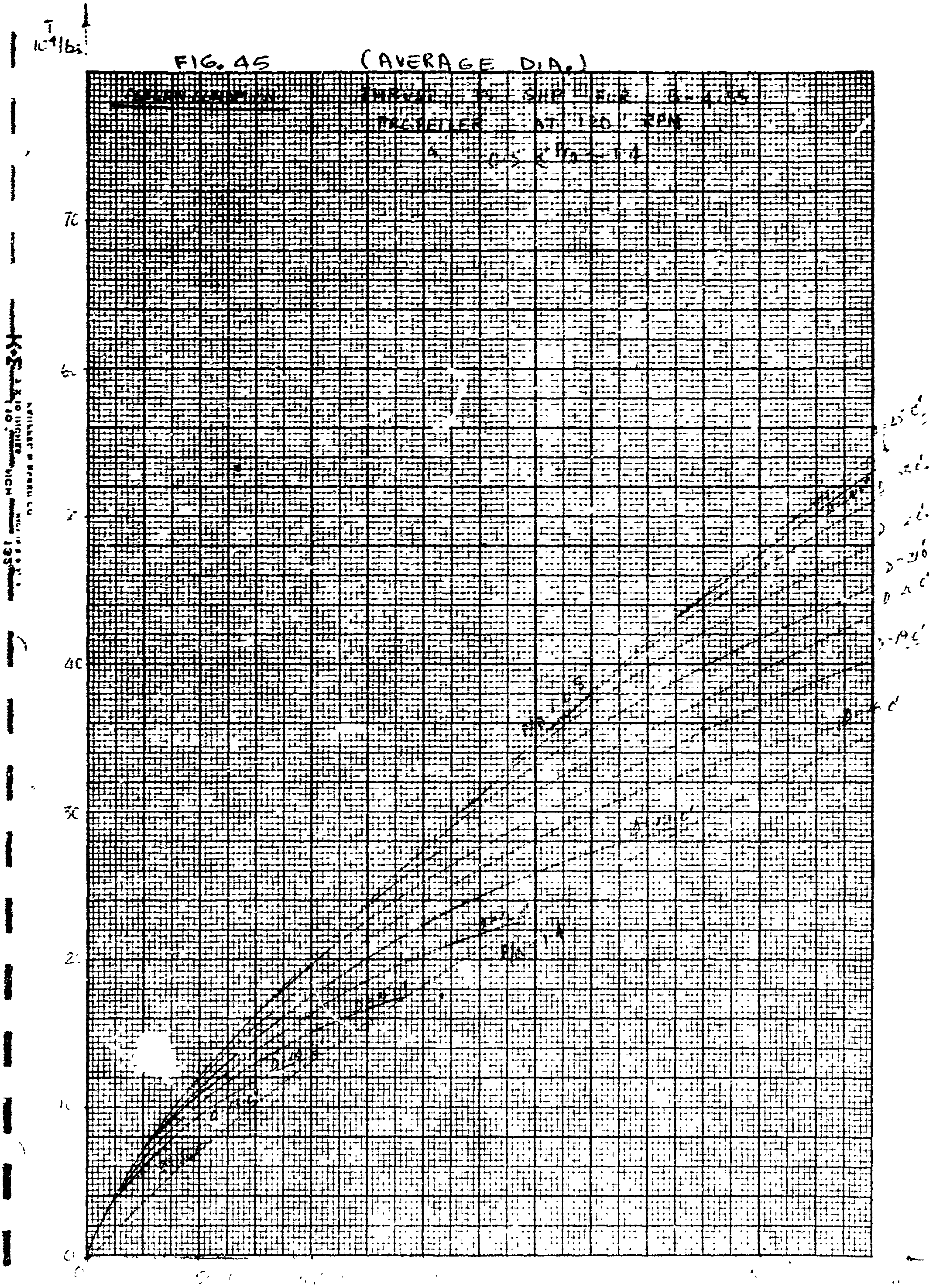
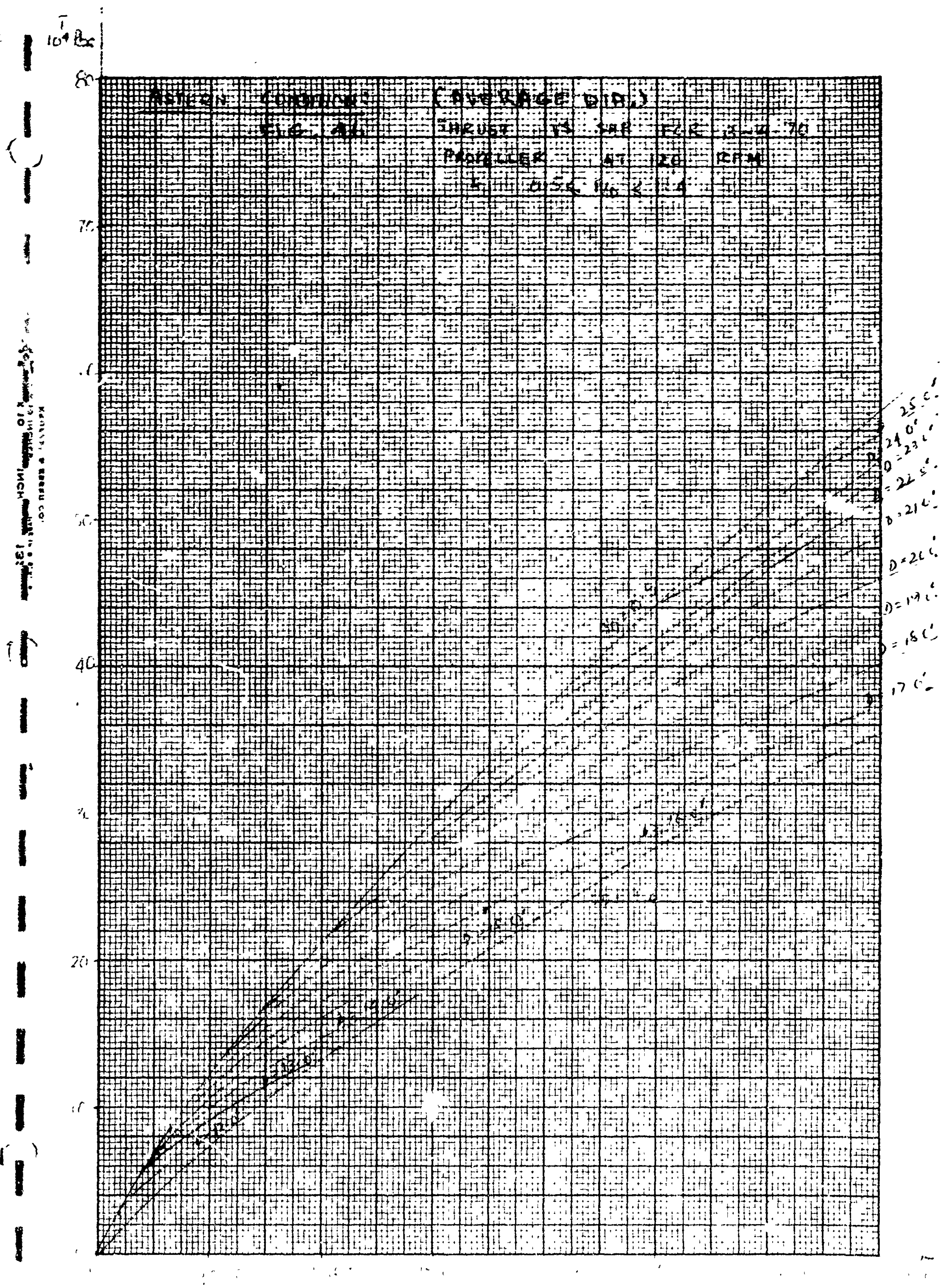
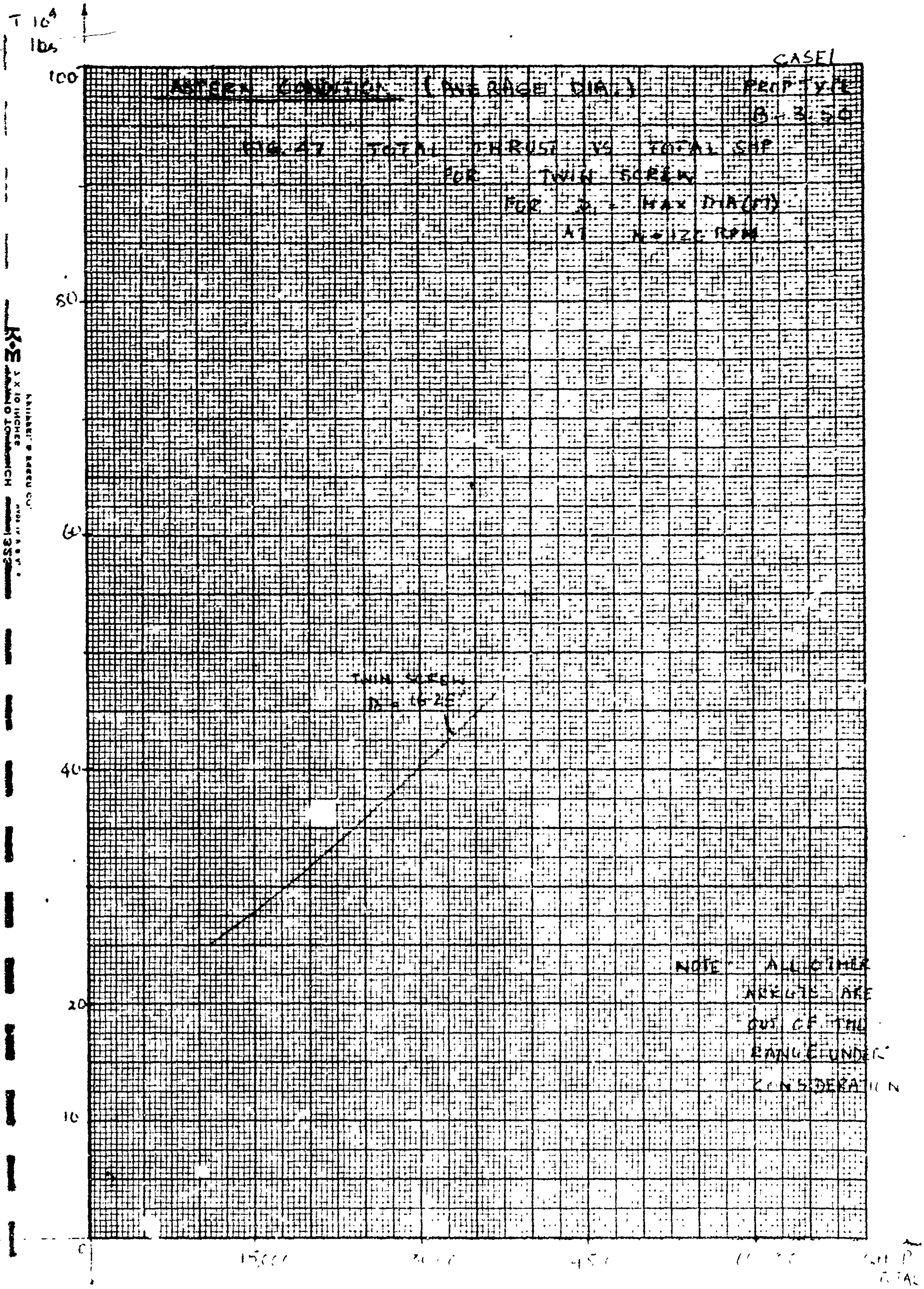

THRUST VS
FOR
NOTE DIAMETERS IN FT
T
10^4 lbs
70
60
50
40
30
20
10
0
5000
10,000
15,000
20,000
30,000

FIG. 45 (AVERAGE DIA.)

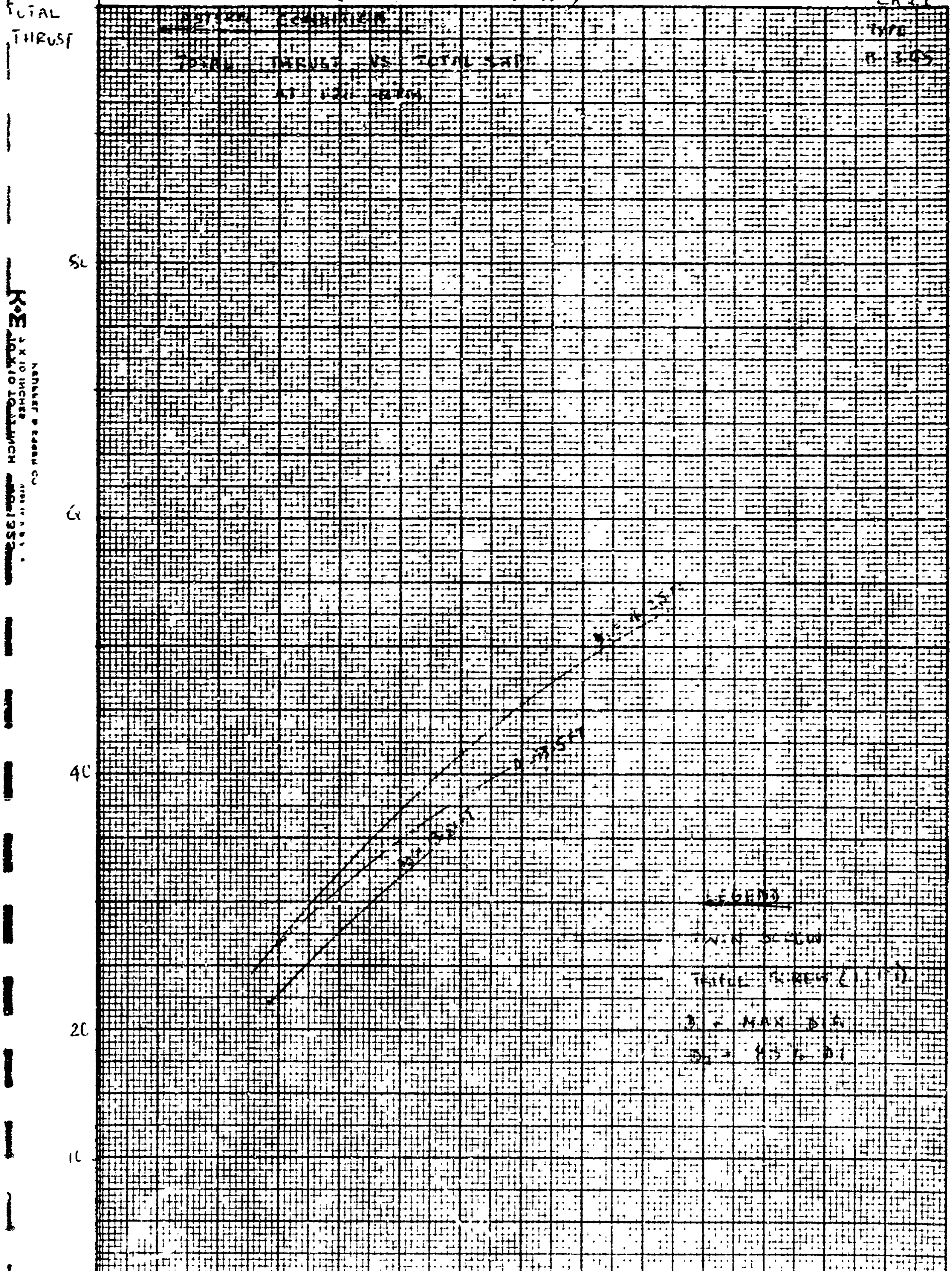


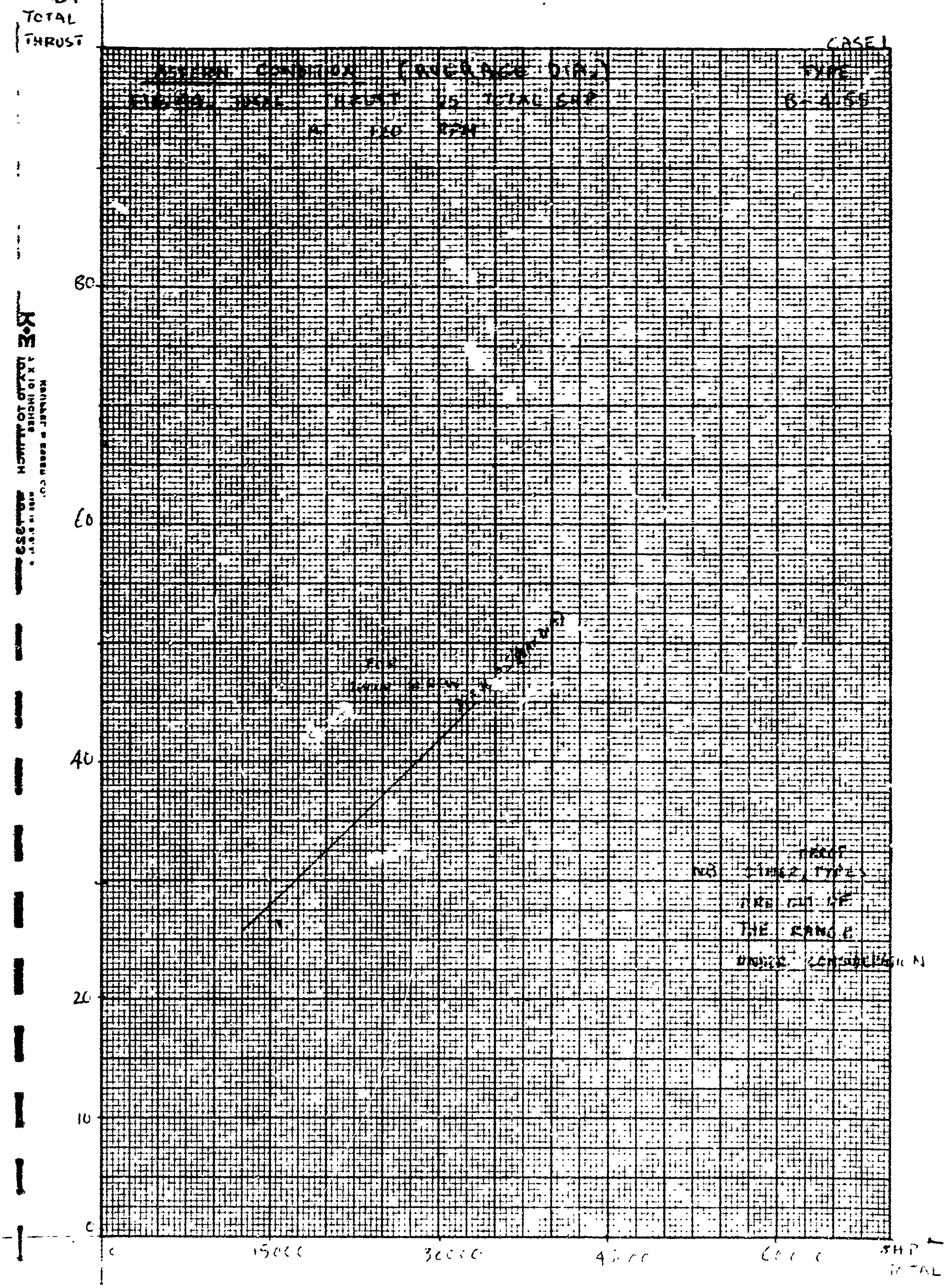

ASTERN CONDITION (AVERAGE DIAL)
FIG. 41
THRUST VS SHP FOR 3-4-70
PROPELLER AT 120 RPM
D = 25 C°
D = 24 C°
D = 23 C°
D = 22 C°
D = 21 C°
D = 20 C°
D = 19 C°
D = 18 C°
D = 17 C°
80
70
60
50
40
30
20
10



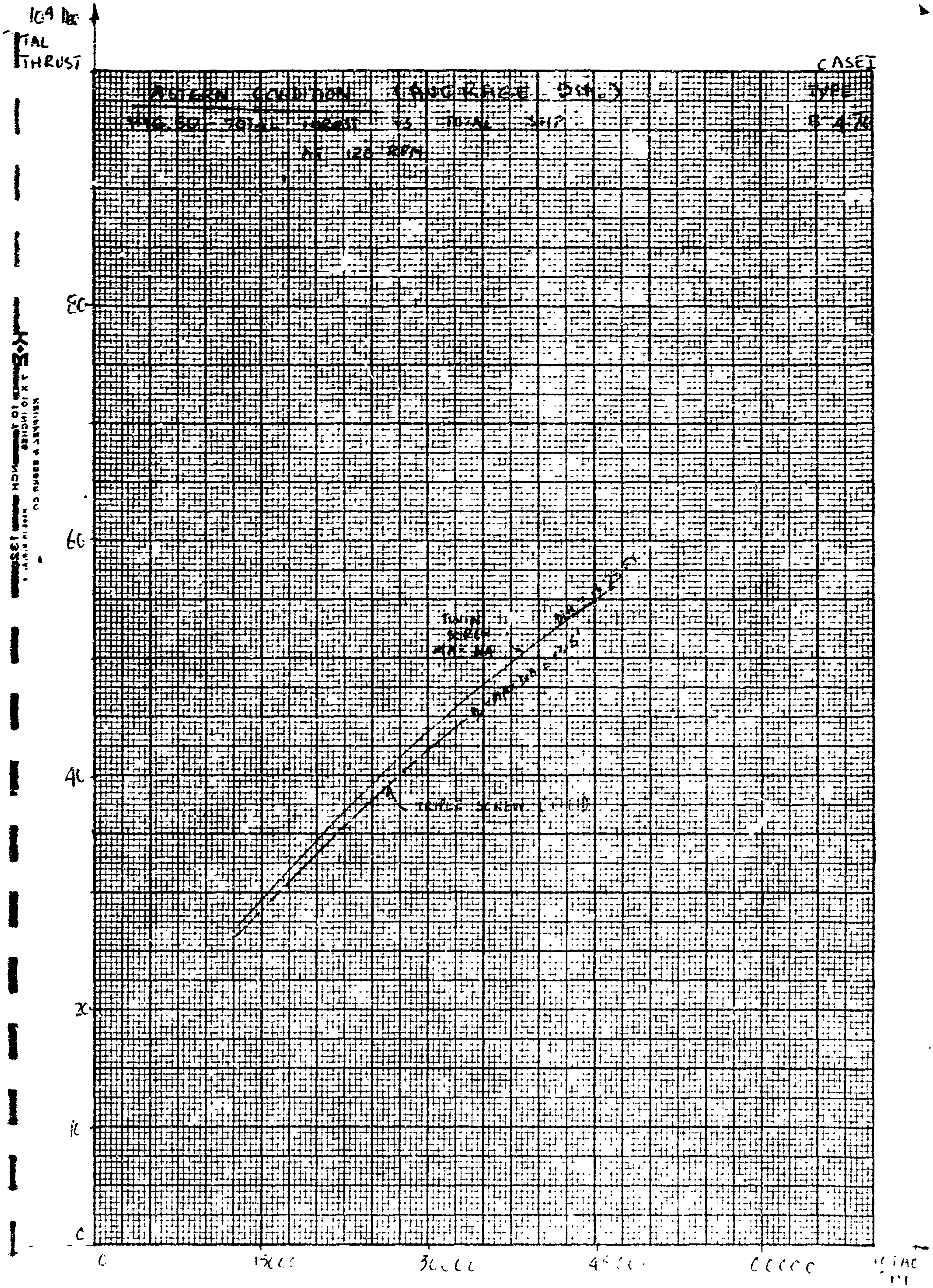
T 10^4 lbs
CASE I
ASTERN CONDITION (AVERAGE DIA.)
PROP TYPE B-3.50
FIG. 47 TOTAL THRUST VS TOTAL SHP
FOR TWIN SCREW
AT N = 120 RPM
TWIN SCREW
100
80
60
40
20
10
0
NOTE: ALL OTHER
ARE
OUT OF THE
RANGE UNDER
CONSIDERATION
SHP

FIG. 48 (AVERAGE DIA.)





TOTAL
THRUST
CASE 1
TYPE
B-4.55
80
60
40
20
10
0
15000
30000
SHP
TOTAL
THE RANGE



TOTAL THRUST
CASE I
TYPE
80
60
40
20
10
0
TWIN SCREW
TRIPLE SCREW

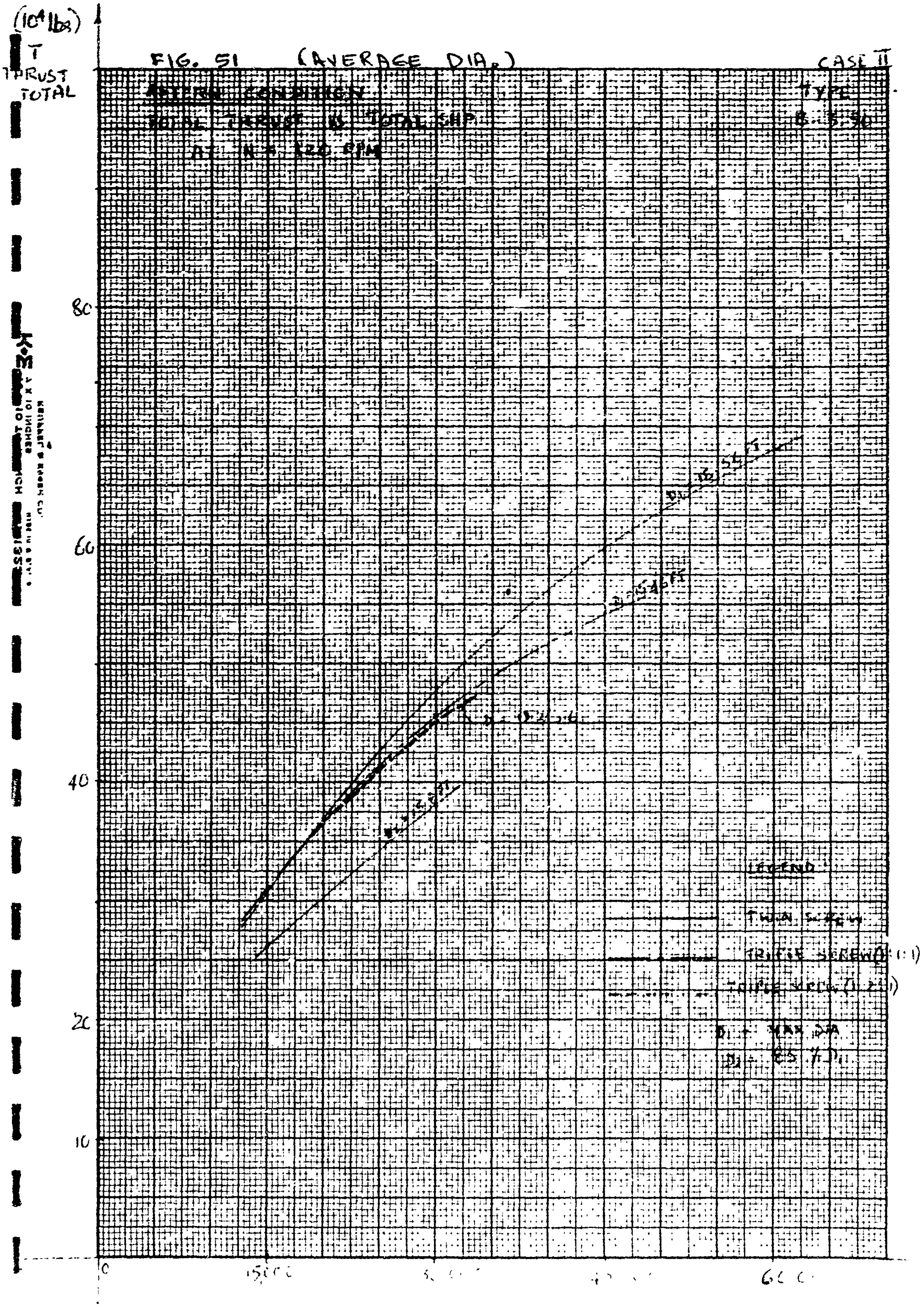
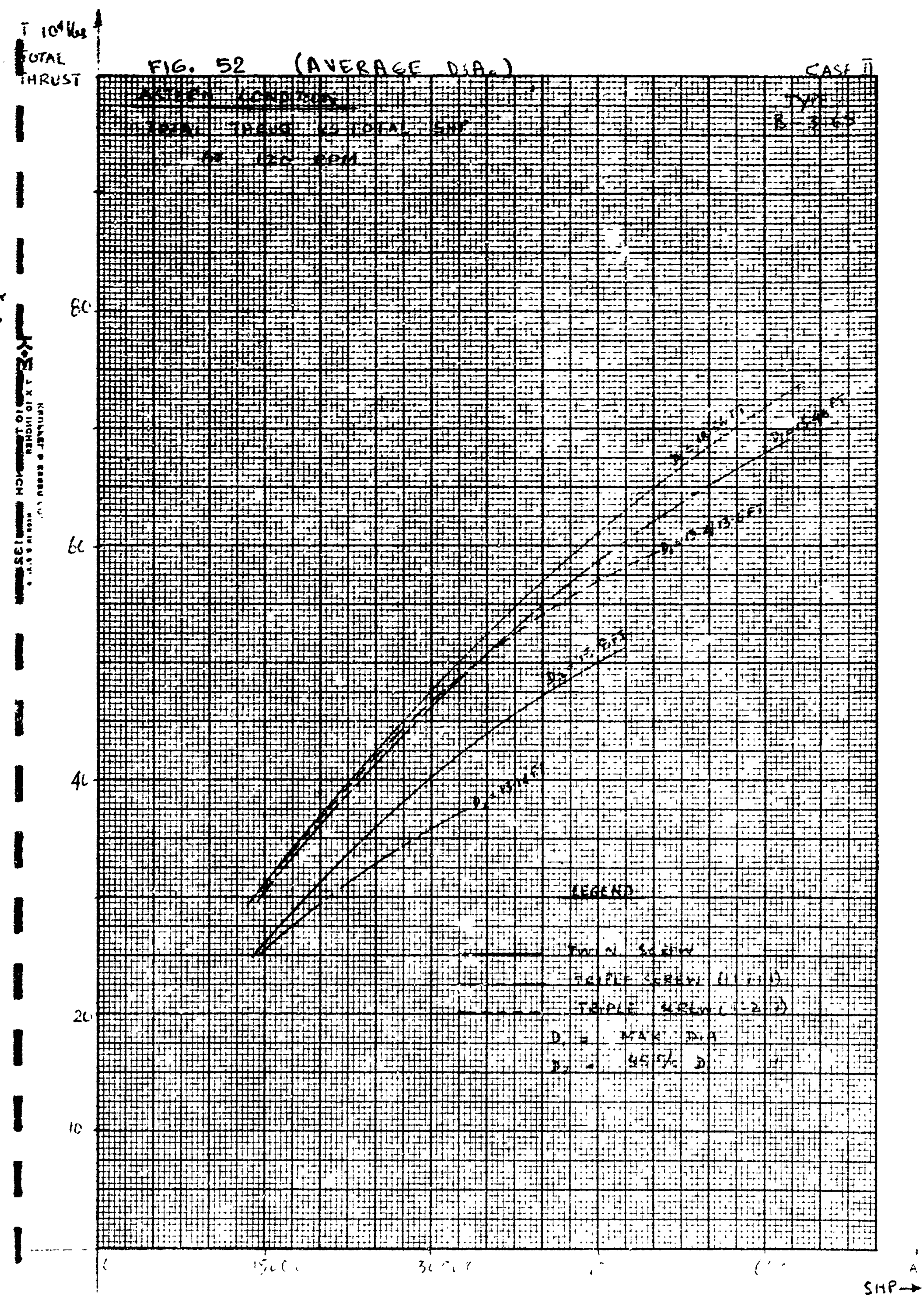
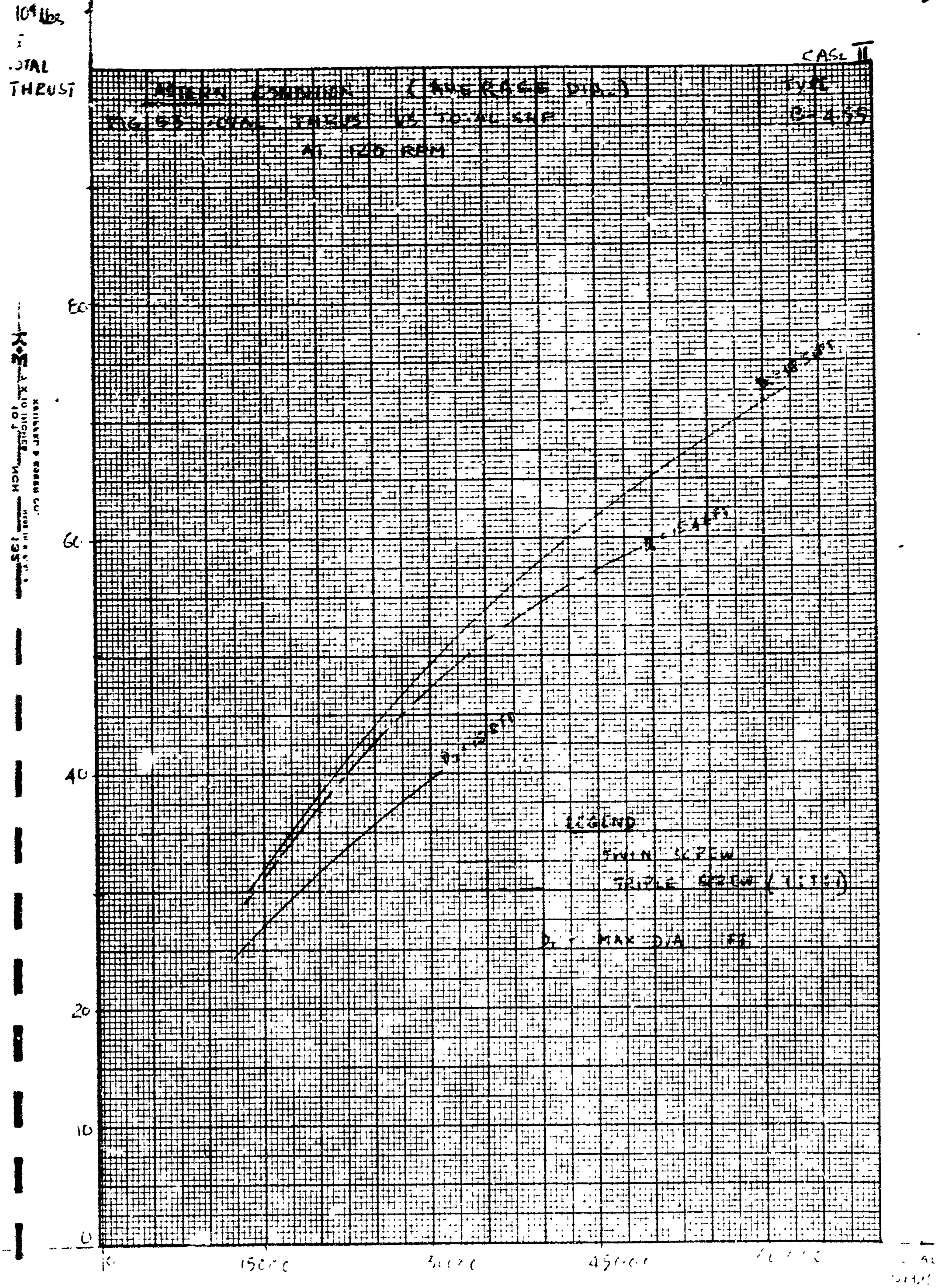


FIG. 51 (AVERAGE DIA.)
CASE II
TYPE
(10^4 lbs)
T
THRUST
TOTAL
80
60
40
20
10
0
1500
6000
LEGEND
TWIN SCREW

FIG. 52 (AVERAGE DIA.)




CASE II
AT 120 RPM
THRUST
LEGEND
0
10
20
40
60
15000
30000
45000

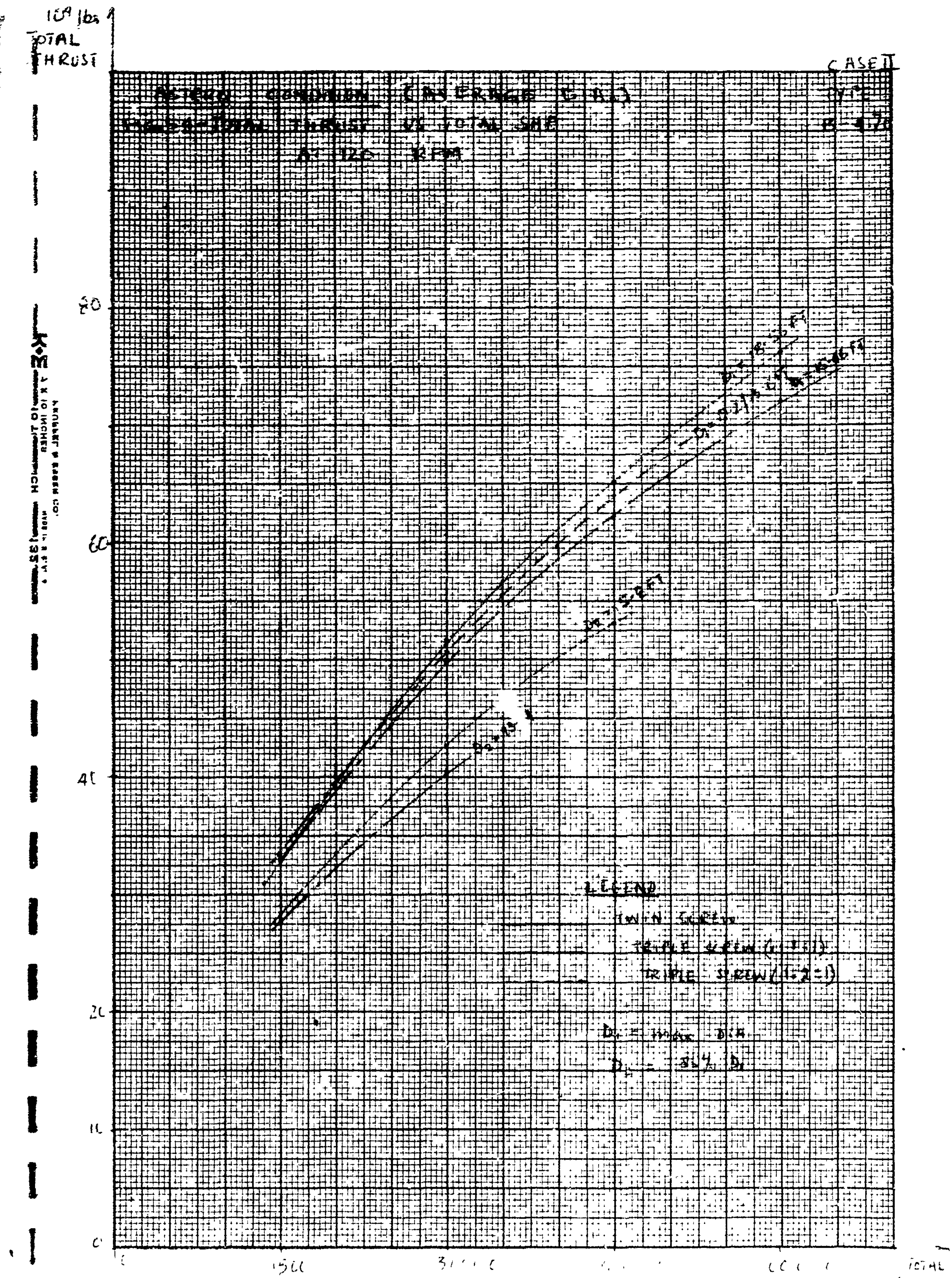


FIG. 55

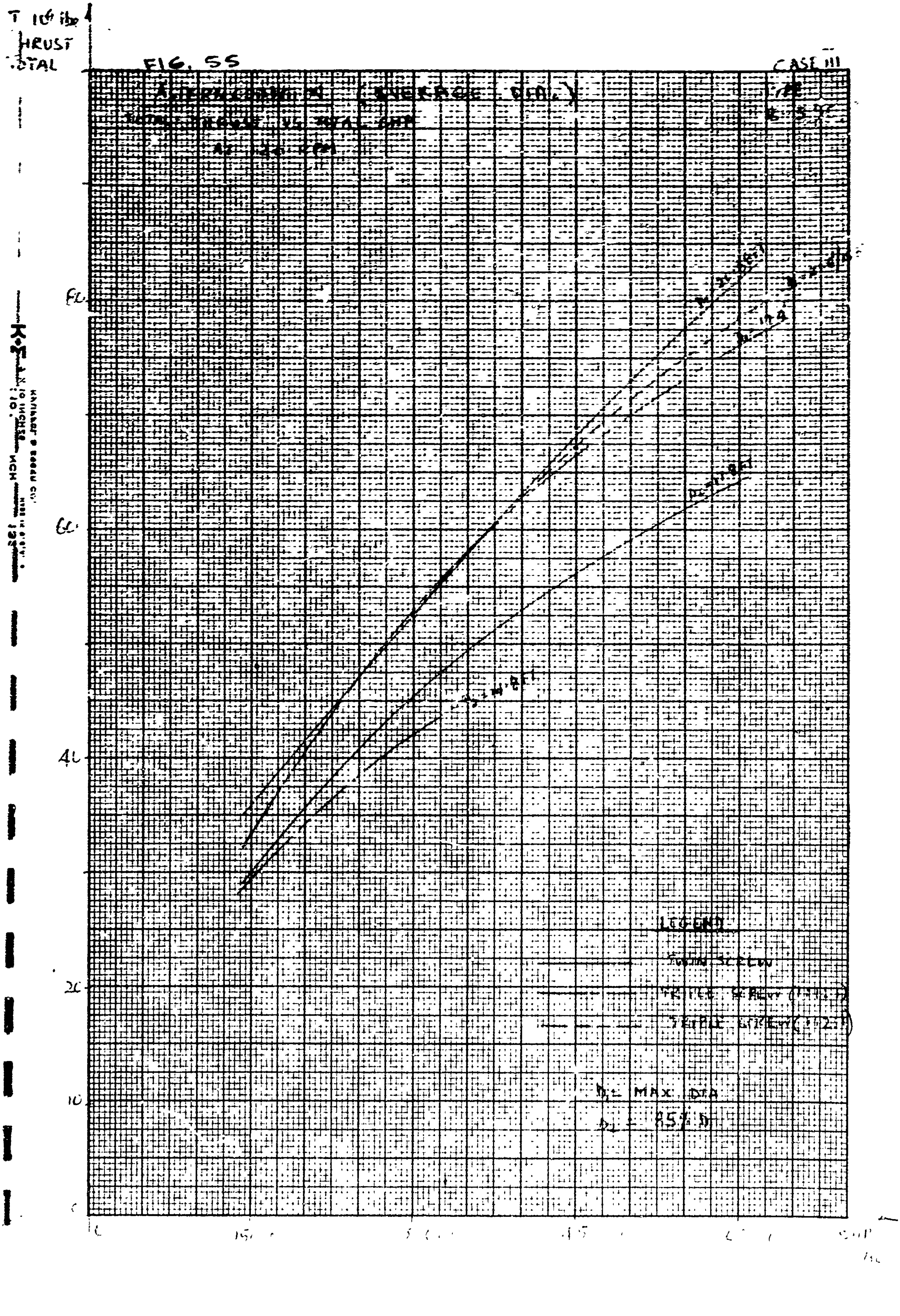
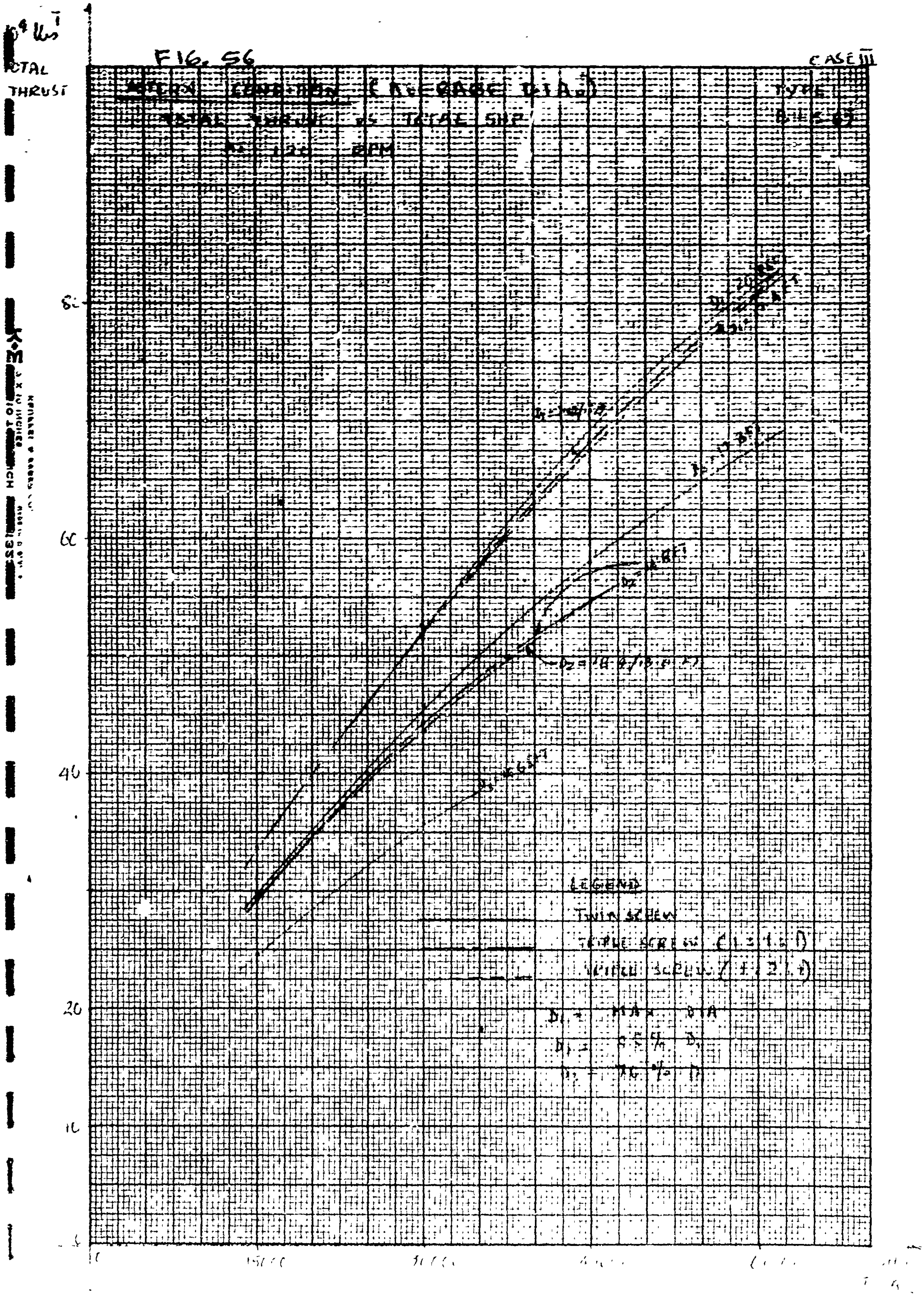
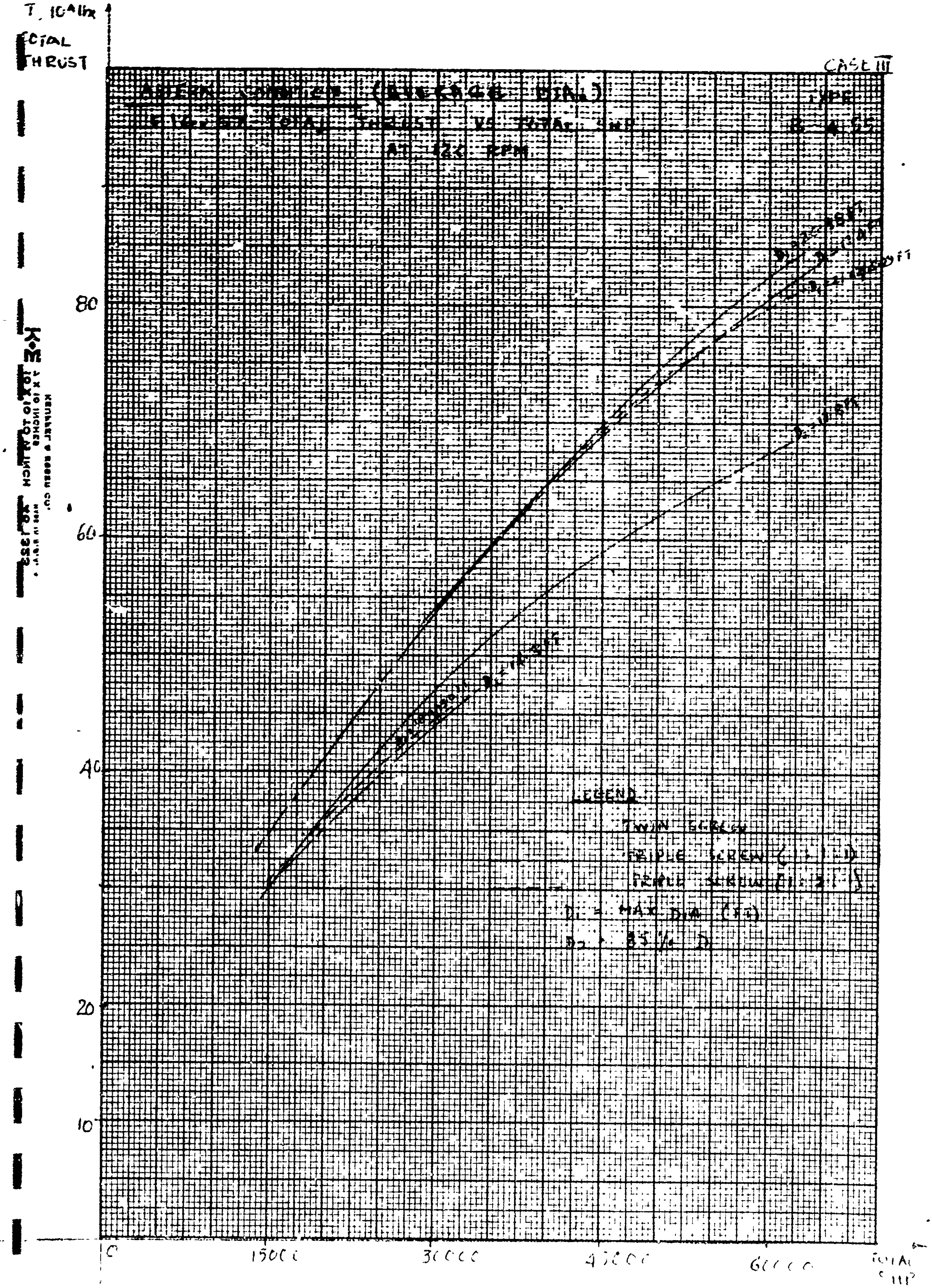
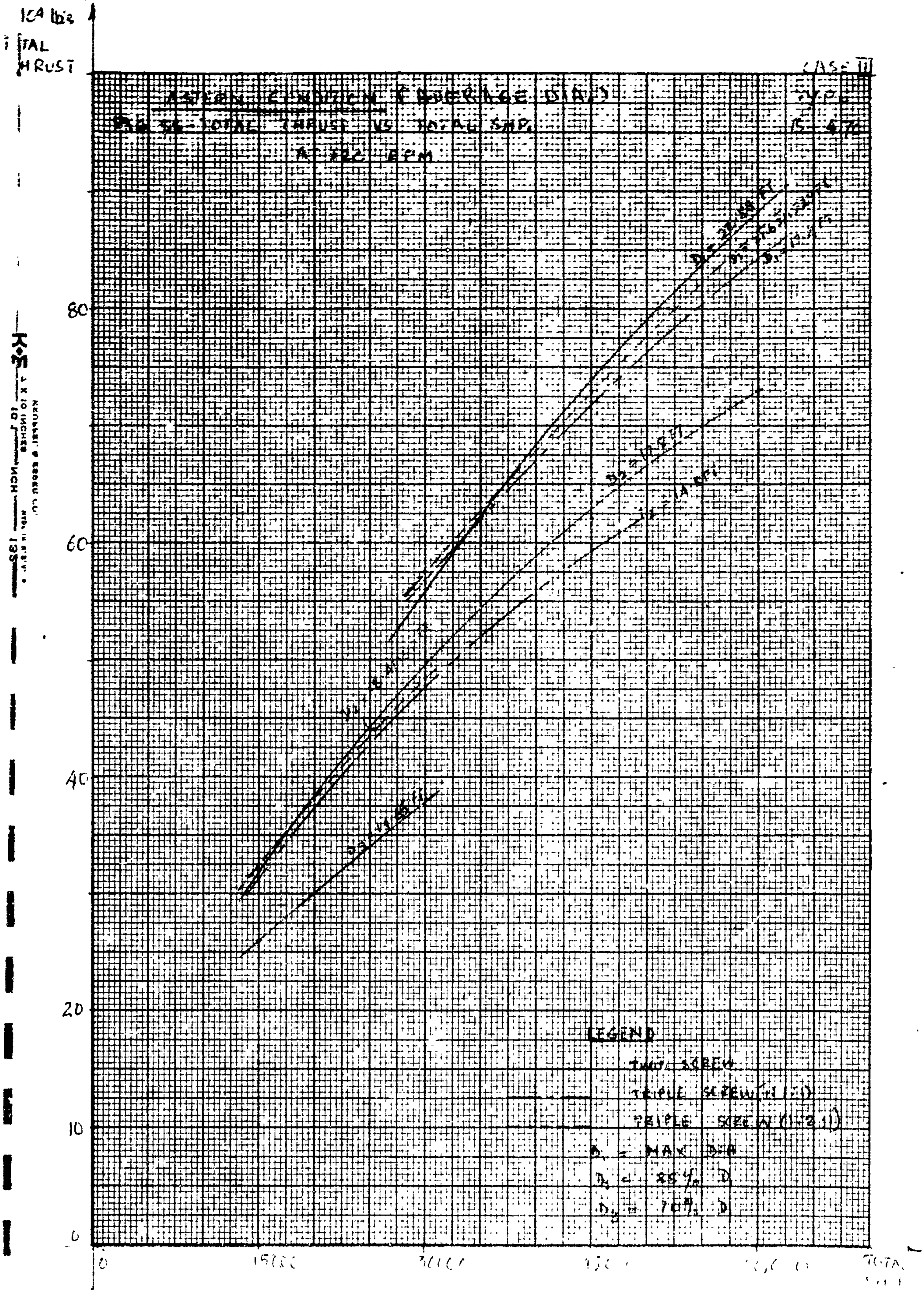

CASE III
T 10⁴ lbs
THRUST
TOTAL
LEGEND
TWIN SCREW
TRIPLE SCREW
D₁ = MAX. DIA
D₂ = 85% D

FIG. 56

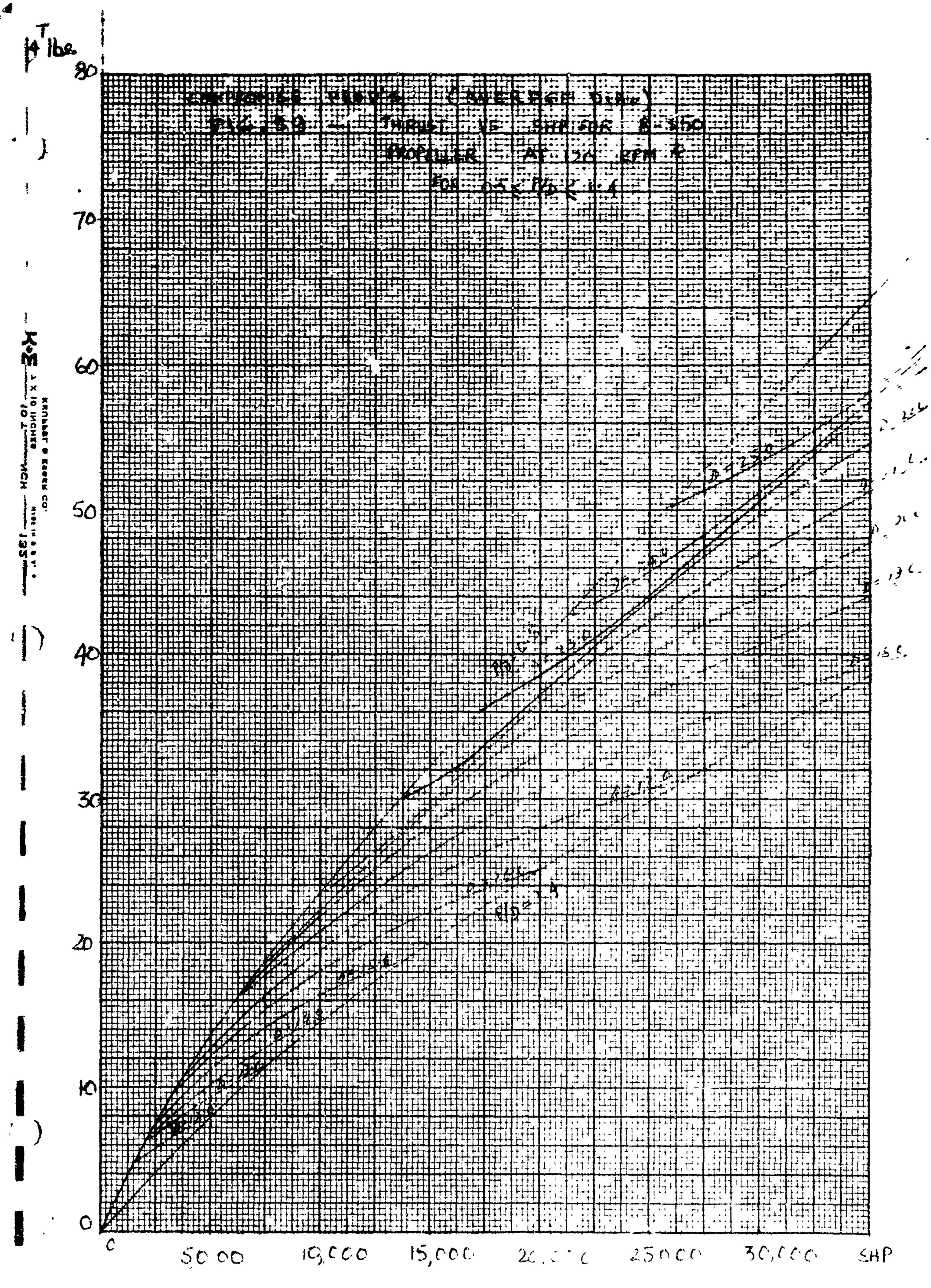




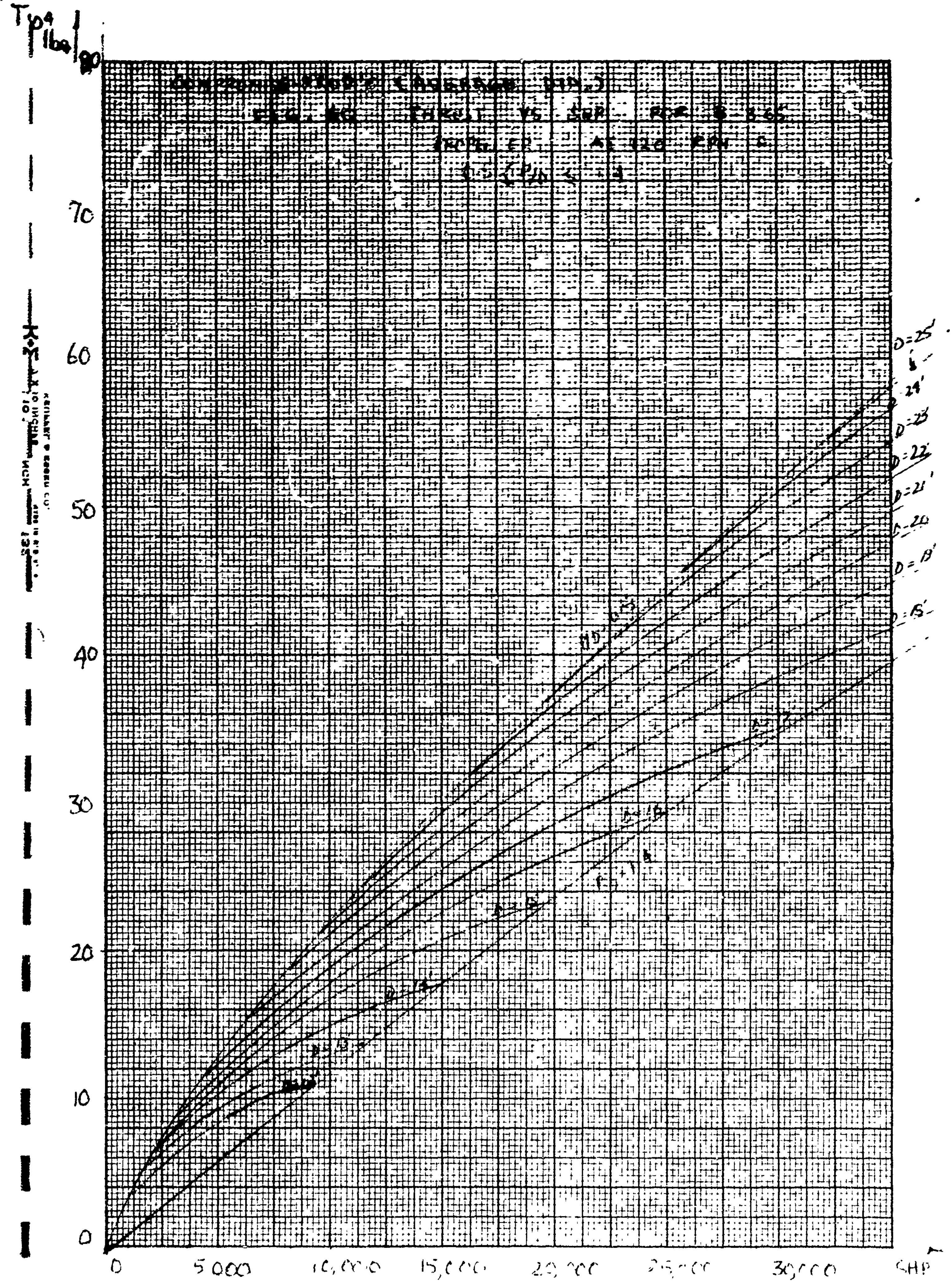
T, 10⁴ lbs
TOTAL THRUST
CASE III
AT 120 RPM
80
60
40
20
10
LEGEND
TWIN SCREW
D₁ = MAX DIA (FT)
D₂ = 85% D₁
0
15000
30000
45000
60000
TOTAL SHP



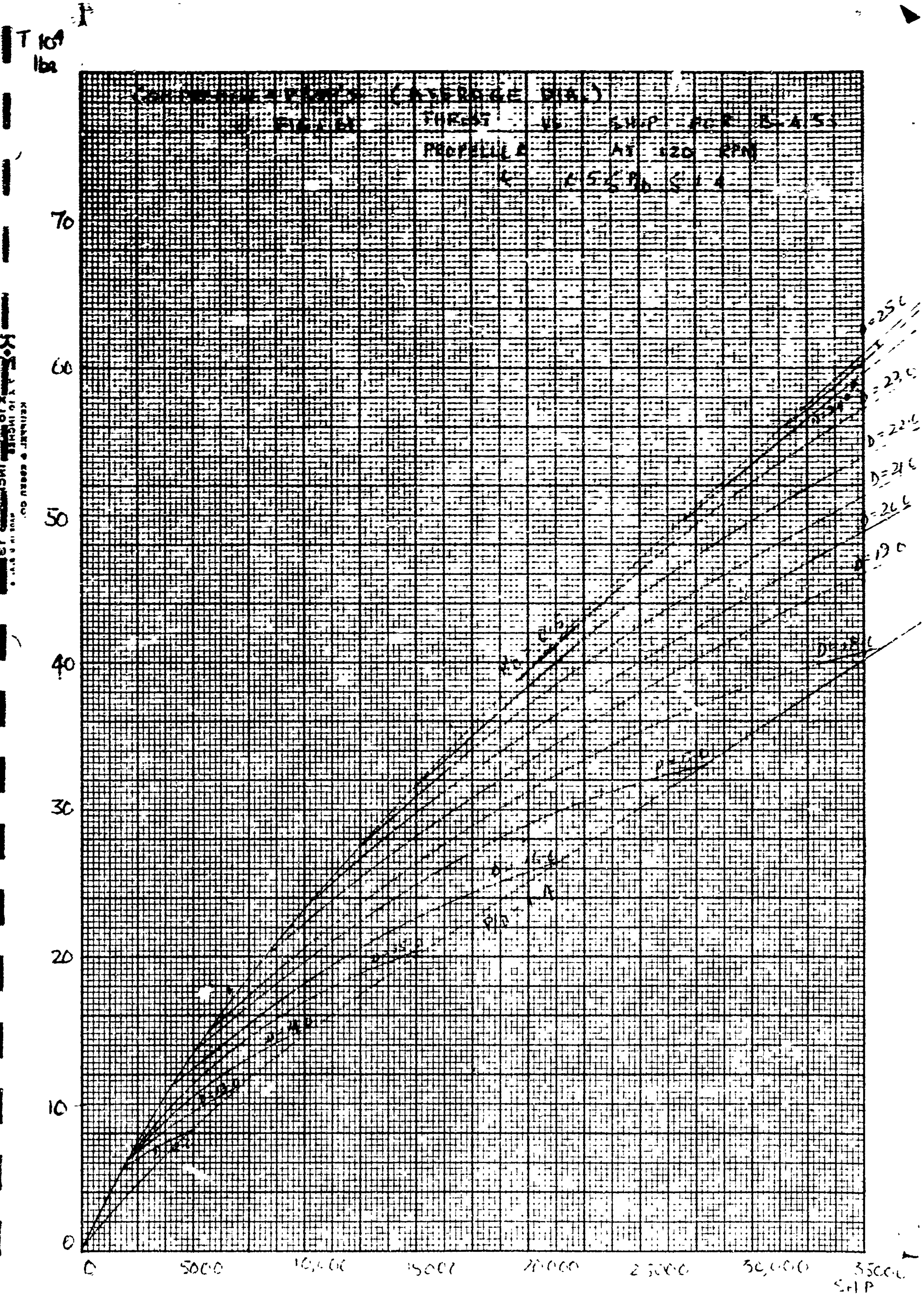
CASE III
TOTAL THRUST VS TOTAL SHP.
LEGEND
TWO SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
MAX DIA
80
60
40
20
10
0



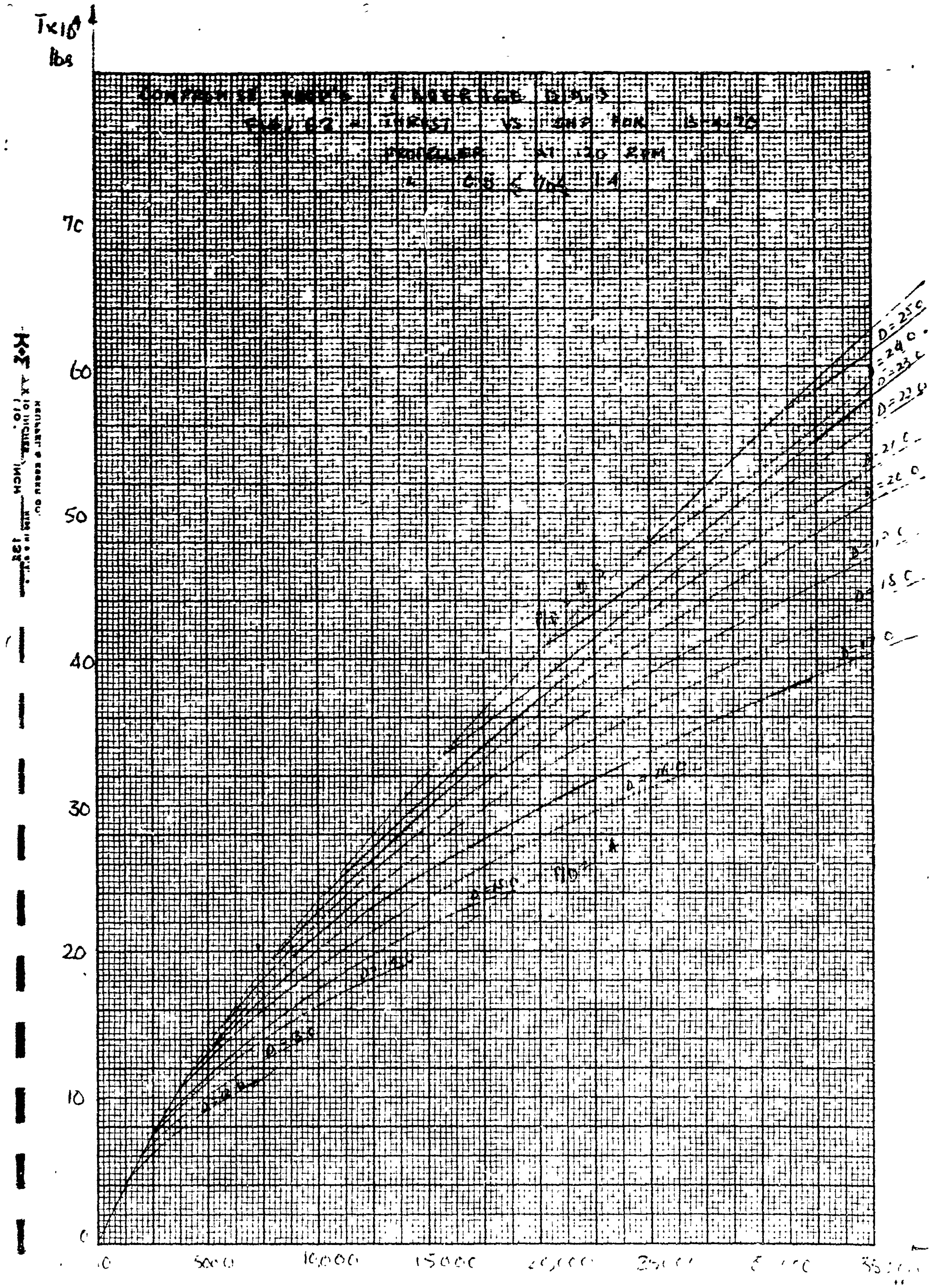
THRUST VS SHP FOR
PROPELLER AT
T lbs
0
10
20
30
40
50
60
70
80
0
5000
10,000
15,000
25000
30,000
SHP



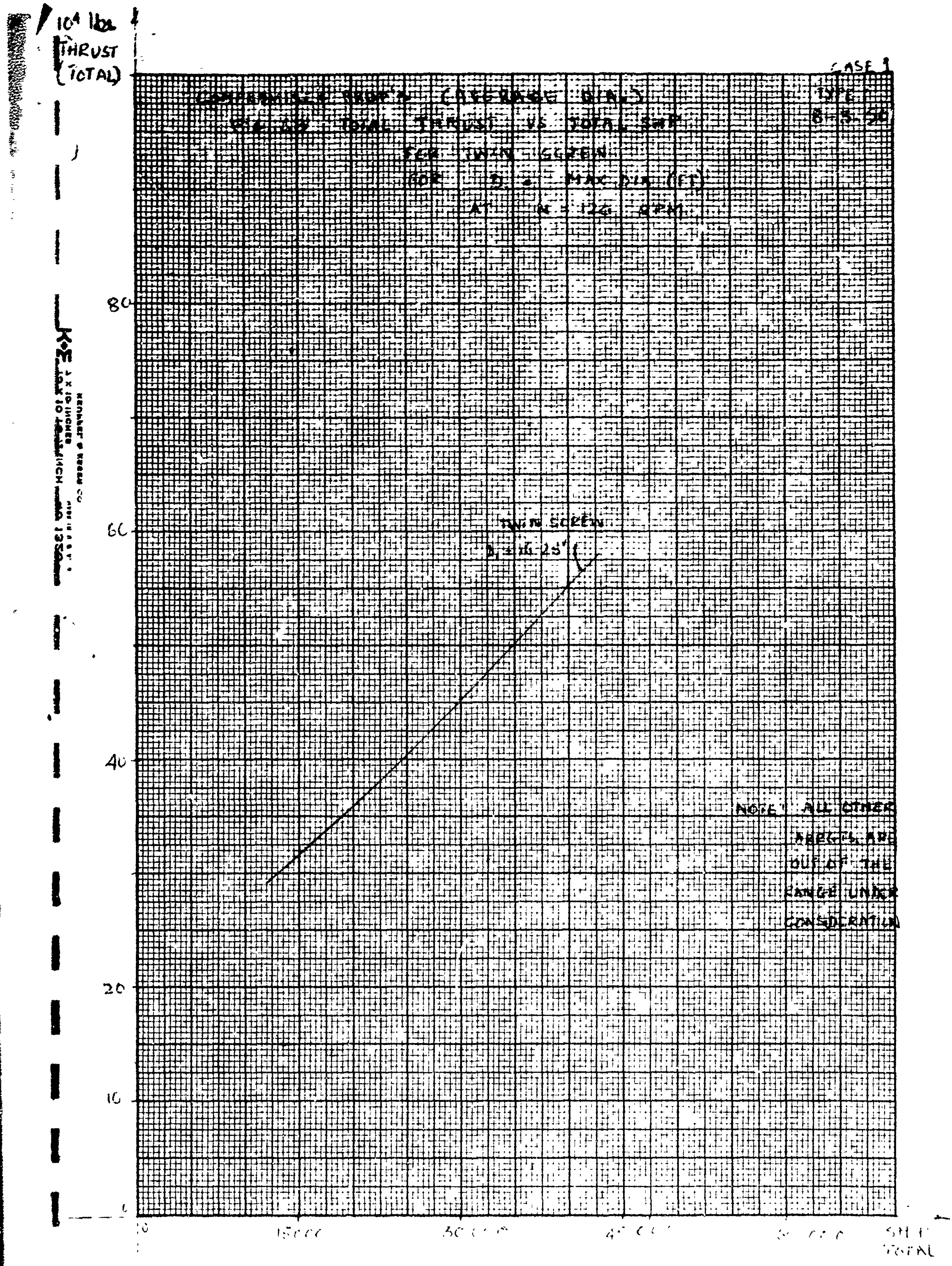
THRUST VS SHP
T
lbs
80
70
60
50
40
30
20
10
0
0
5000
10,000
15,000
20,000
30,000
SHP
D=25'
24'
D=23
D=22
D=21'
D=20
D=18'
D=15'



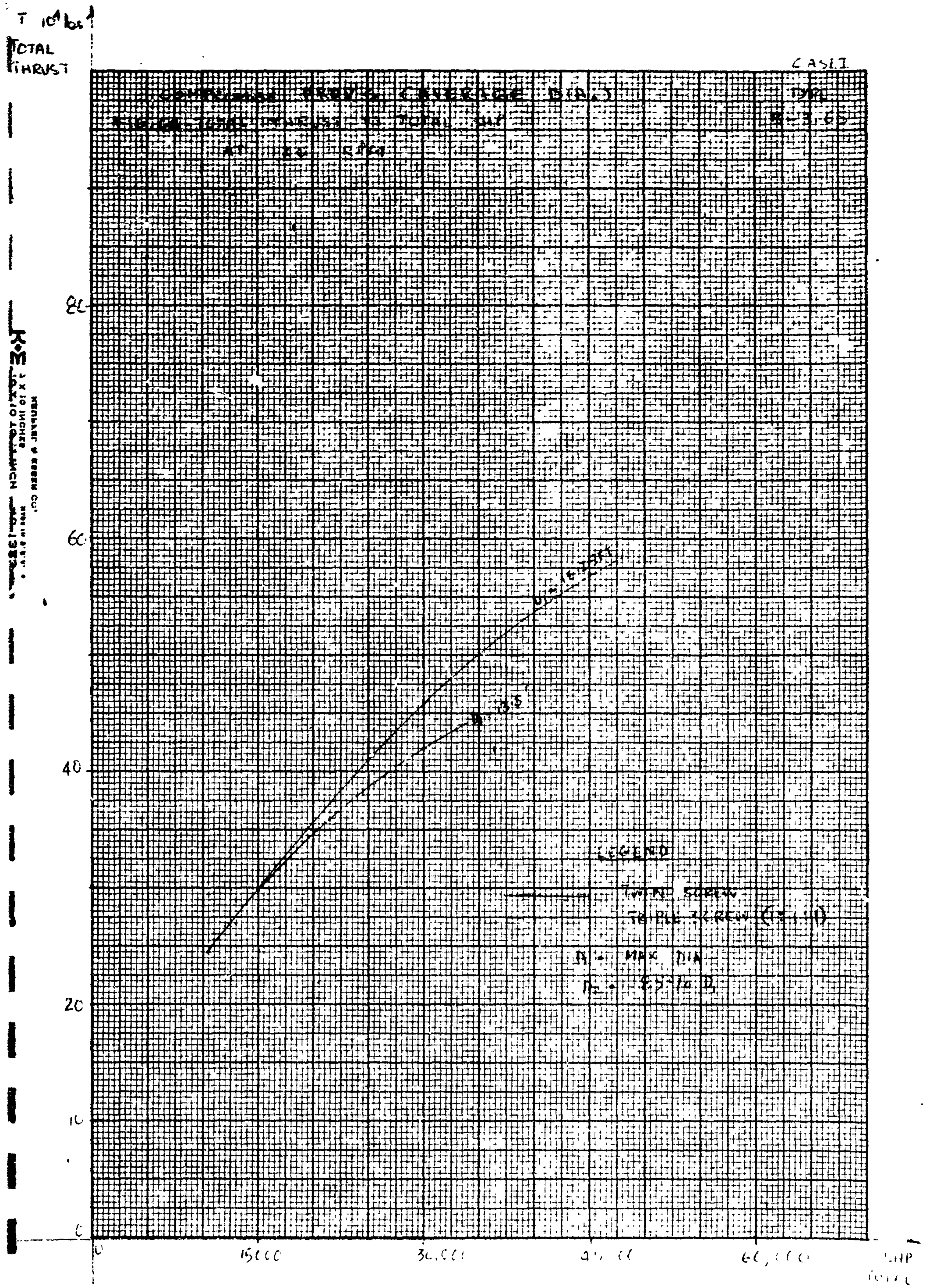
T 10⁴ lbs
THRUST
VS
SHP
PROPELLER
AT
120
RPM
70
60
50
40
30
20
10
0
5000
10,000
15000
20,000
25000
30,000
35000
SHP
D = 25.0
D = 23.0
D = 22.0
D = 21.0
D = 20.0
D = 19.0
D = 18.0
D = 16.0



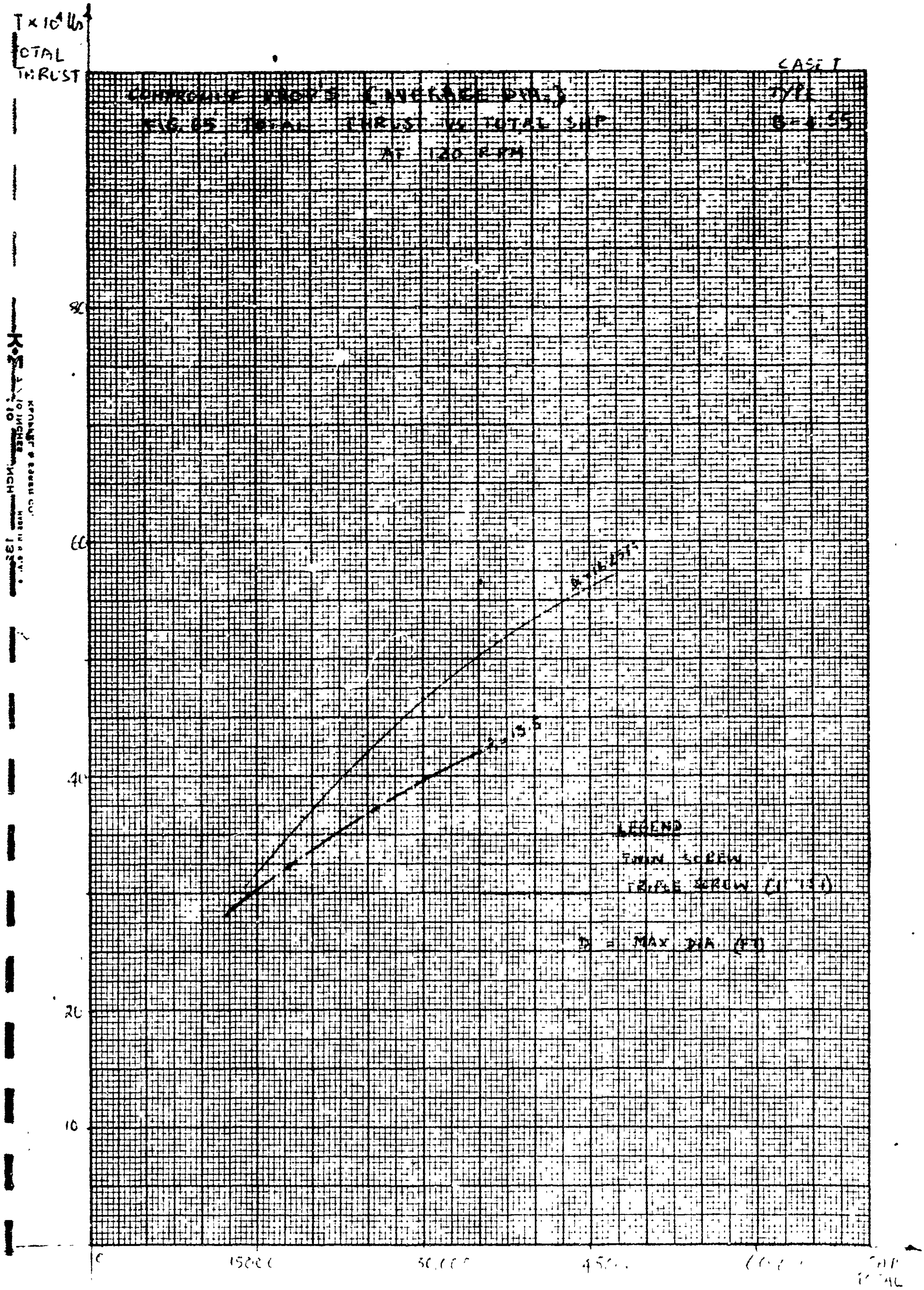
VS
PROPELLER AT 120 RPM
Tx10³
lbs
70
60
50
40
30
20
10
0
0
5000
10,000
15000
D=25.0
D=24.0
D=22.0



10⁴ lbs
THRUST (TOTAL)
CASE 1
TOTAL THRUST VS TOTAL SHP
FOR TWIN SCREW
AT N = 124 RPM
TWIN SCREW
D = 16.25'
NOTE: ALL OTHER
ARE
OUT OF THE
RANGE UNDER
CONSIDERATION
80
60
40
20
10
0
15000
30000
45000
SHP
TOTAL



T 10^4 lbs
TOTAL THRUST
CASE I
AT
80
60
40
20
10
0
LEGEND
TWIN SCREW
TRIPLE SCREW
MAX. DIA
0
15000
30,000
60,000
SHP


T x 10⁴ lbs
TOTAL THRUST
CASE I
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
80
60
40
20
10
0
15000
30,000
LEGEND
TWIN SCREW
D = MAX DIA (FT)

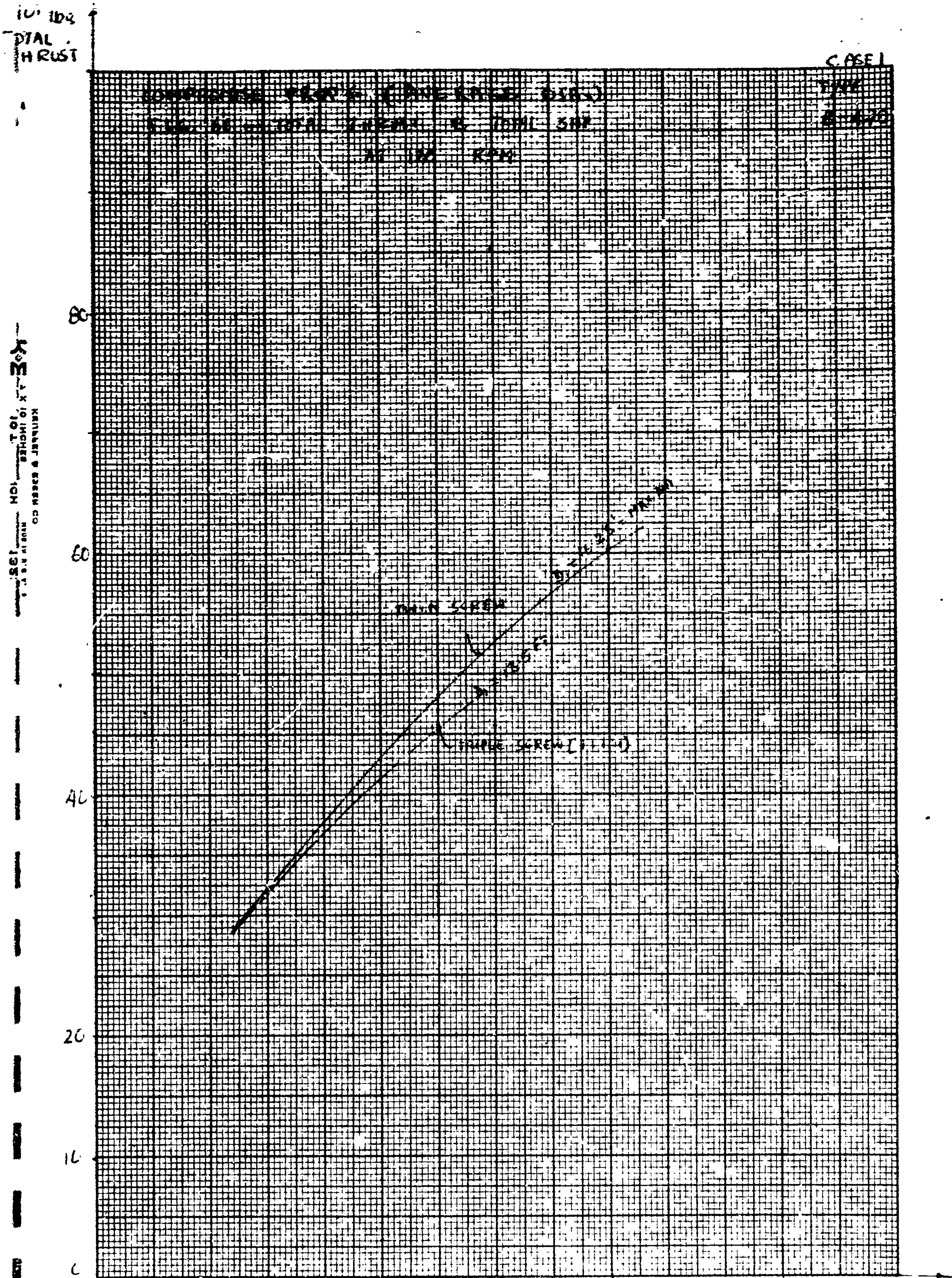

CASE 1
TOTAL THRUST
80
60
40
20
10
0
15000
30,000
60,000
TOTAL SHP
TWIN SCREW
TRIPLE SCREW

FIG. 67:

CASE II

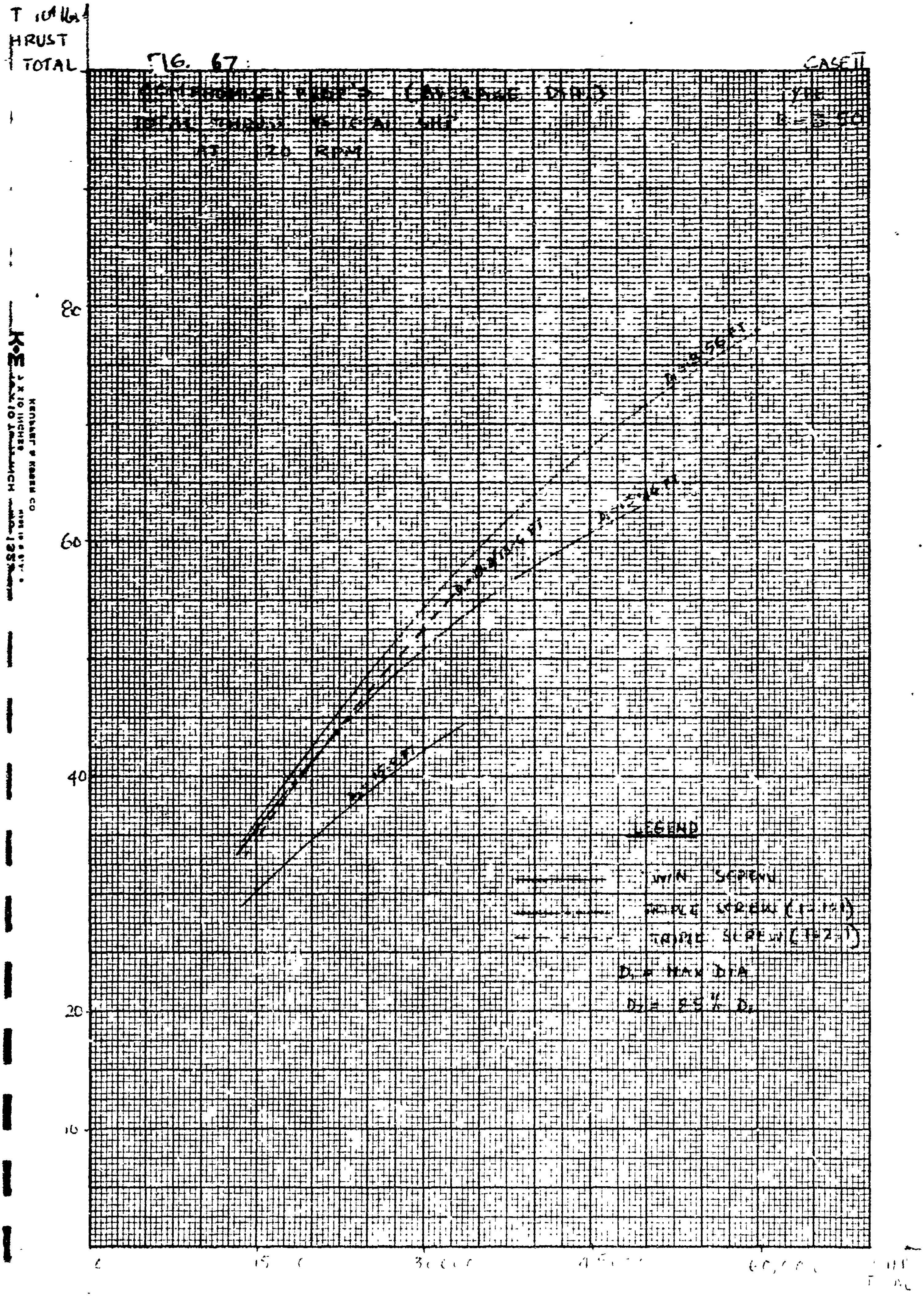
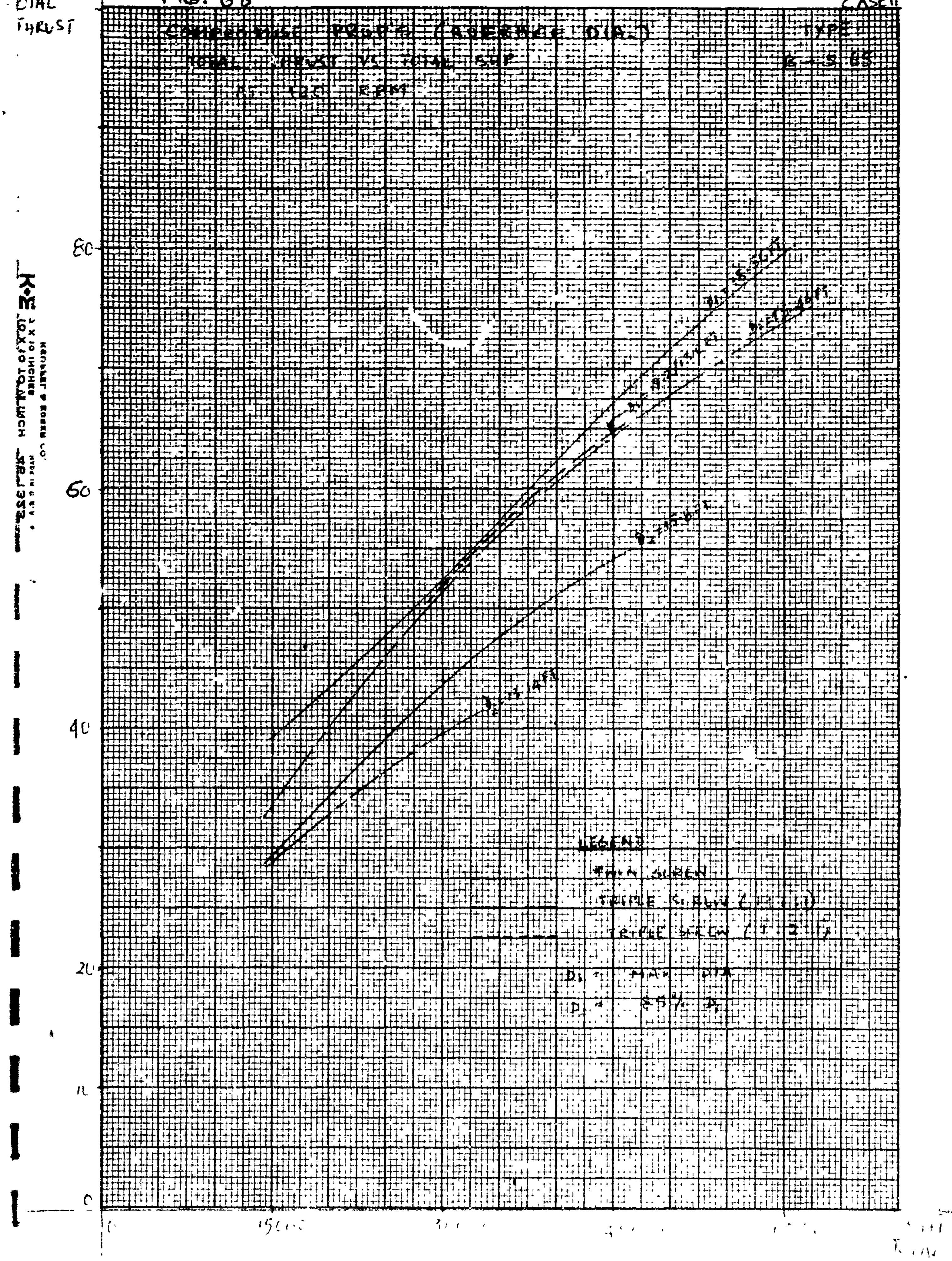
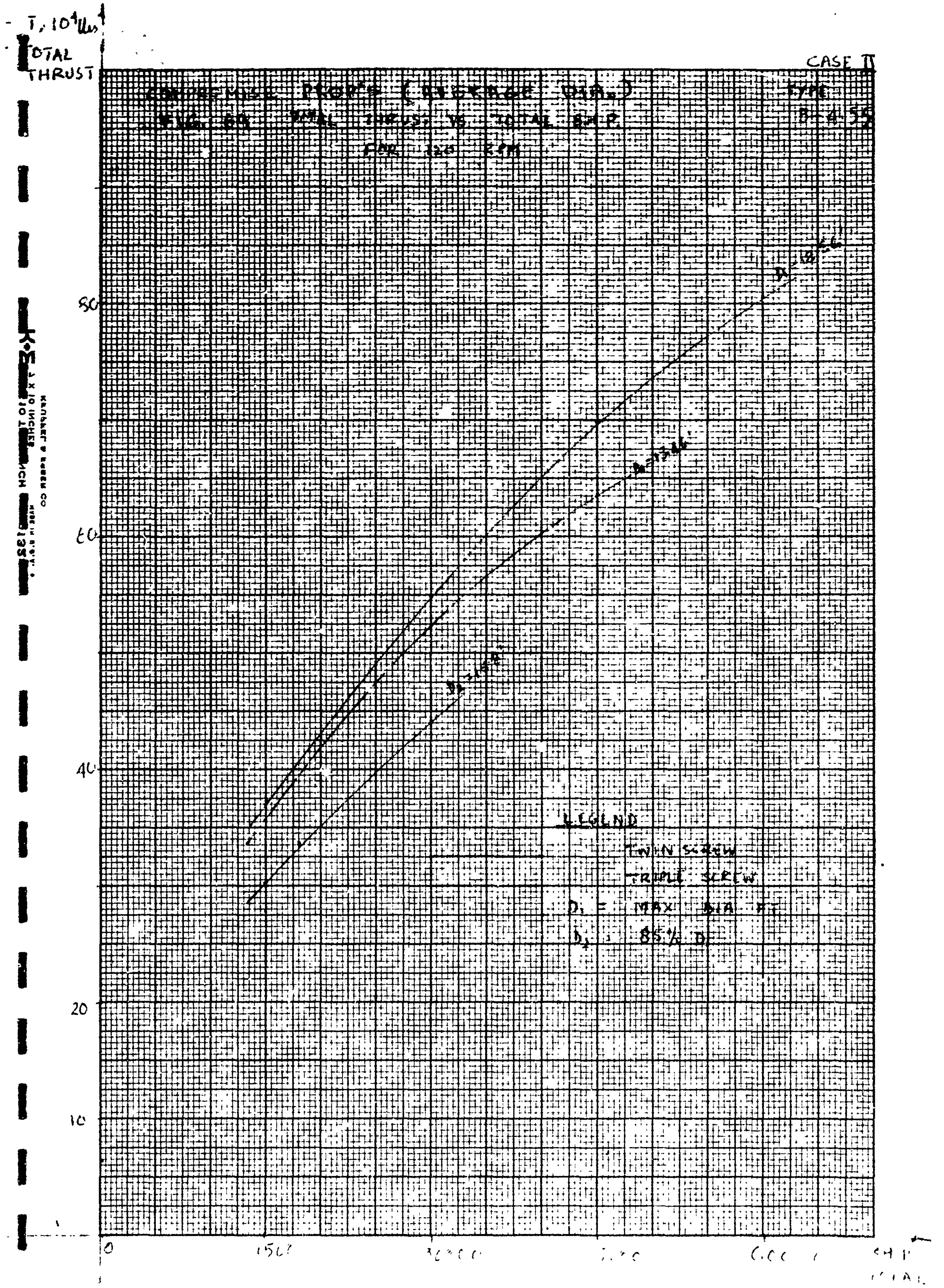
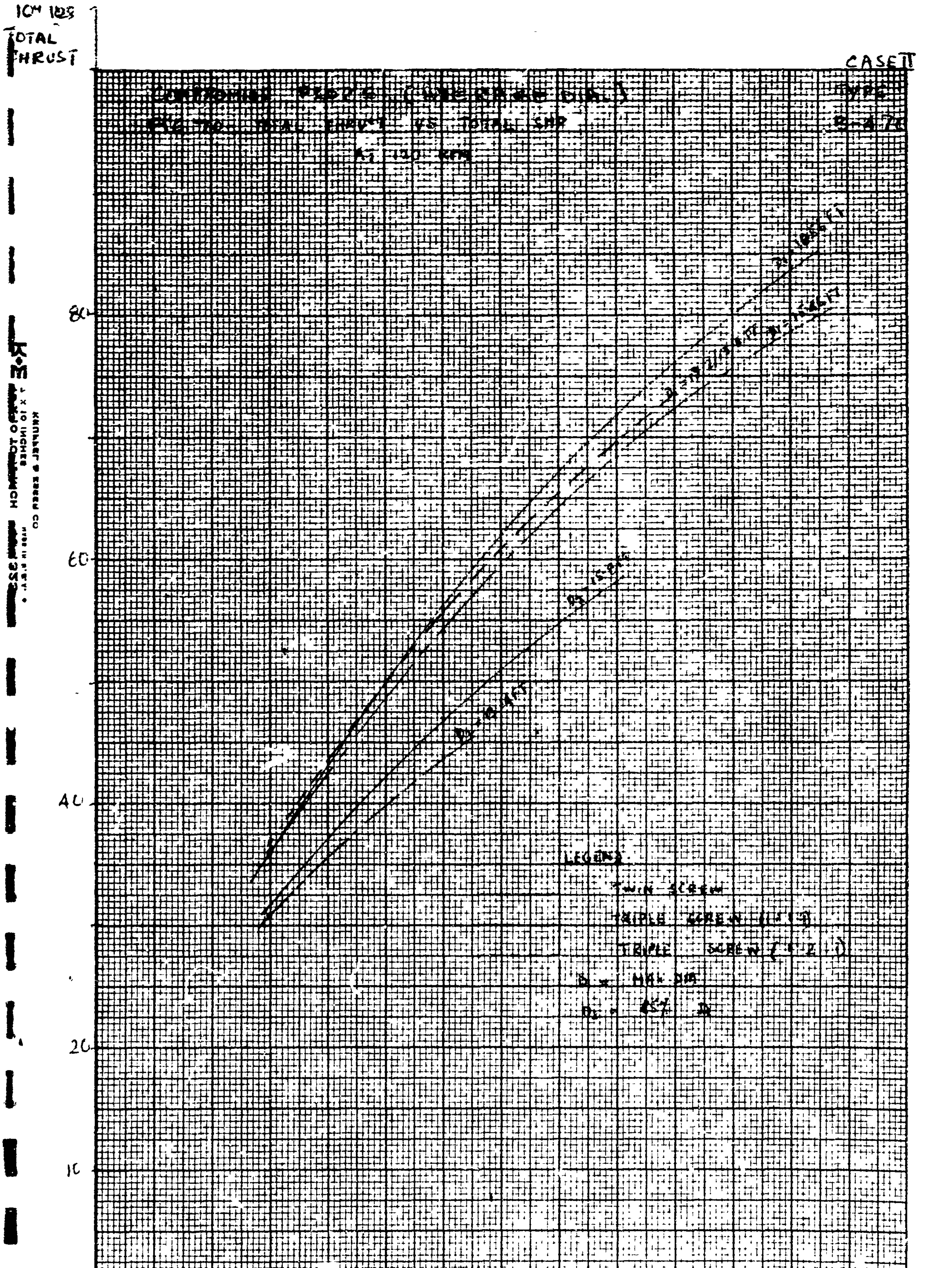


FIG. 68



CASE II
TYPE
6-3.65
TOTAL THRUST
10⁴ lbs
80
60
40
20
0
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW
MAX DIA
85%
1500
SHP


T, 10⁴ lbs
TOTAL THRUST
CASE II
80
60
40
20
10
0
LEGEND
TWIN SCREW
TRIPLE SCREW
D₁ = MAX DIA FT
D₂ = 85% D₁
SHP
TOTAL


TOTAL THRUST
CASE II
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW
80
60
40
20
10
0
0
15000
30000
45000
60000
TOTAL SHP

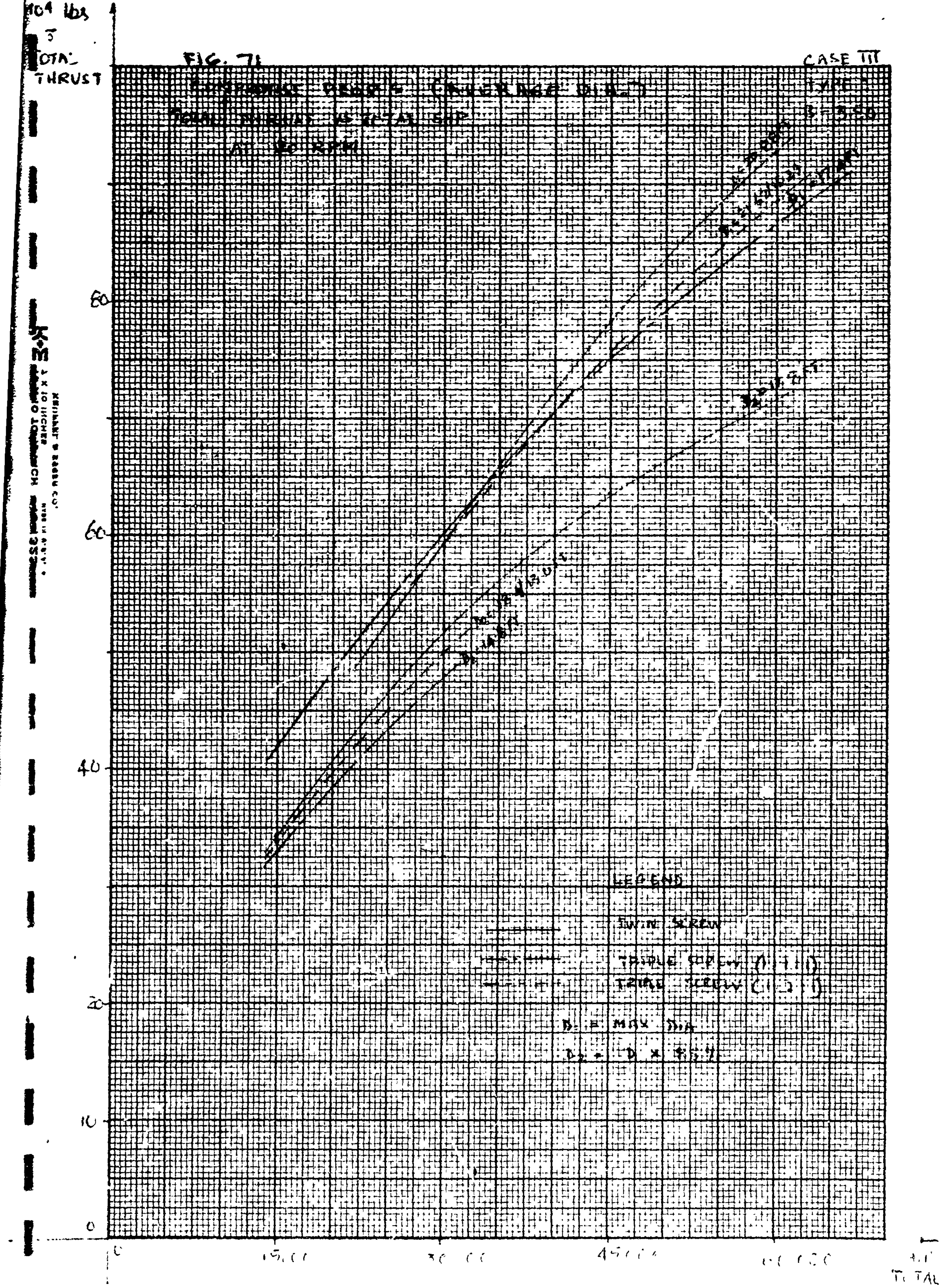
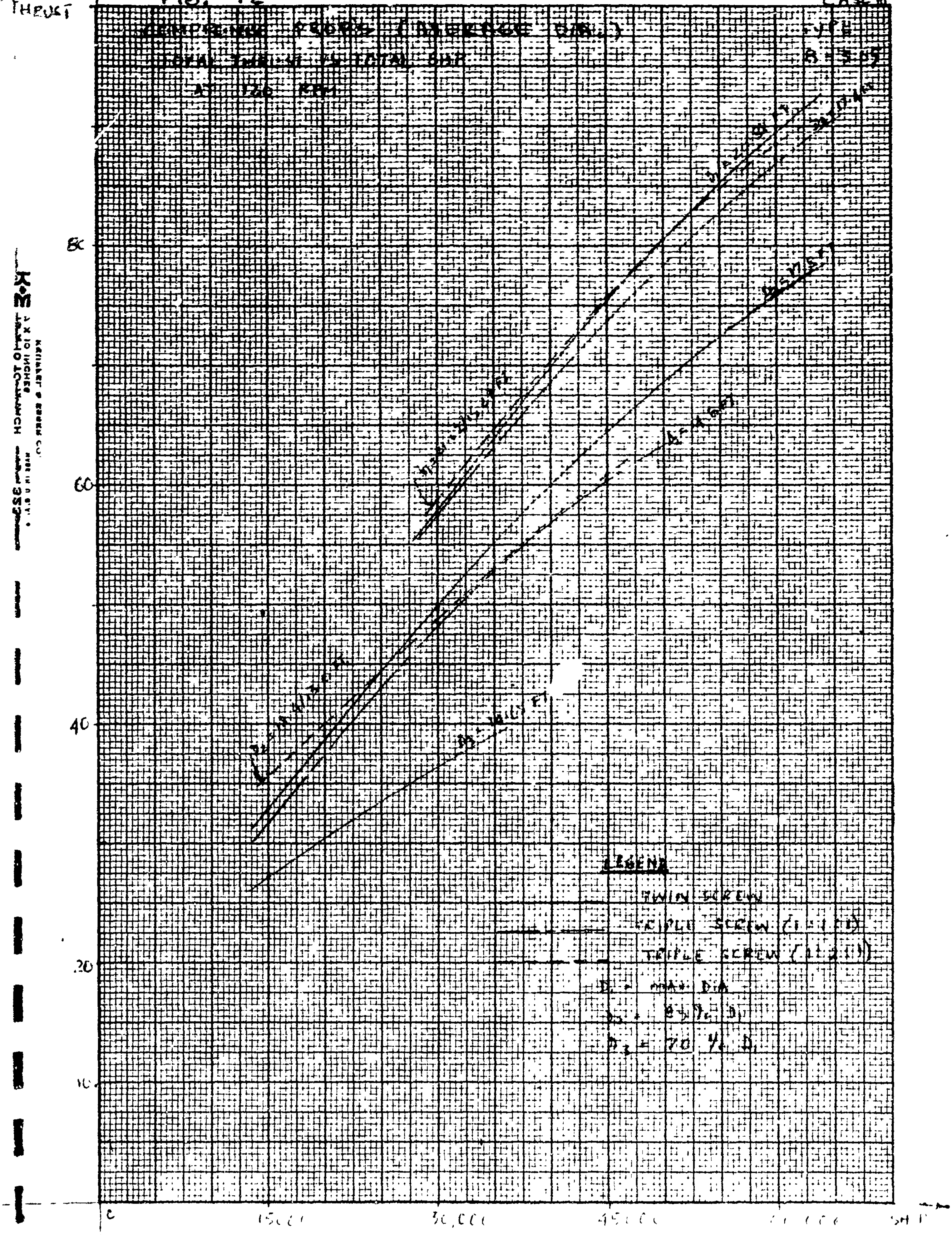


FIG. 71
CASE III
TOTAL THRUST
0
10
20
40
60
80
15,000
30,000
45,000
60,000
TOTAL
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW

FIG. 72



CASE III
TOTAL THRUST
80
60
40
20
10
0
15000
30,000
45000
SHP TOTAL
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW
D_1 = MAX DIA
D_3 = 70 % D_1

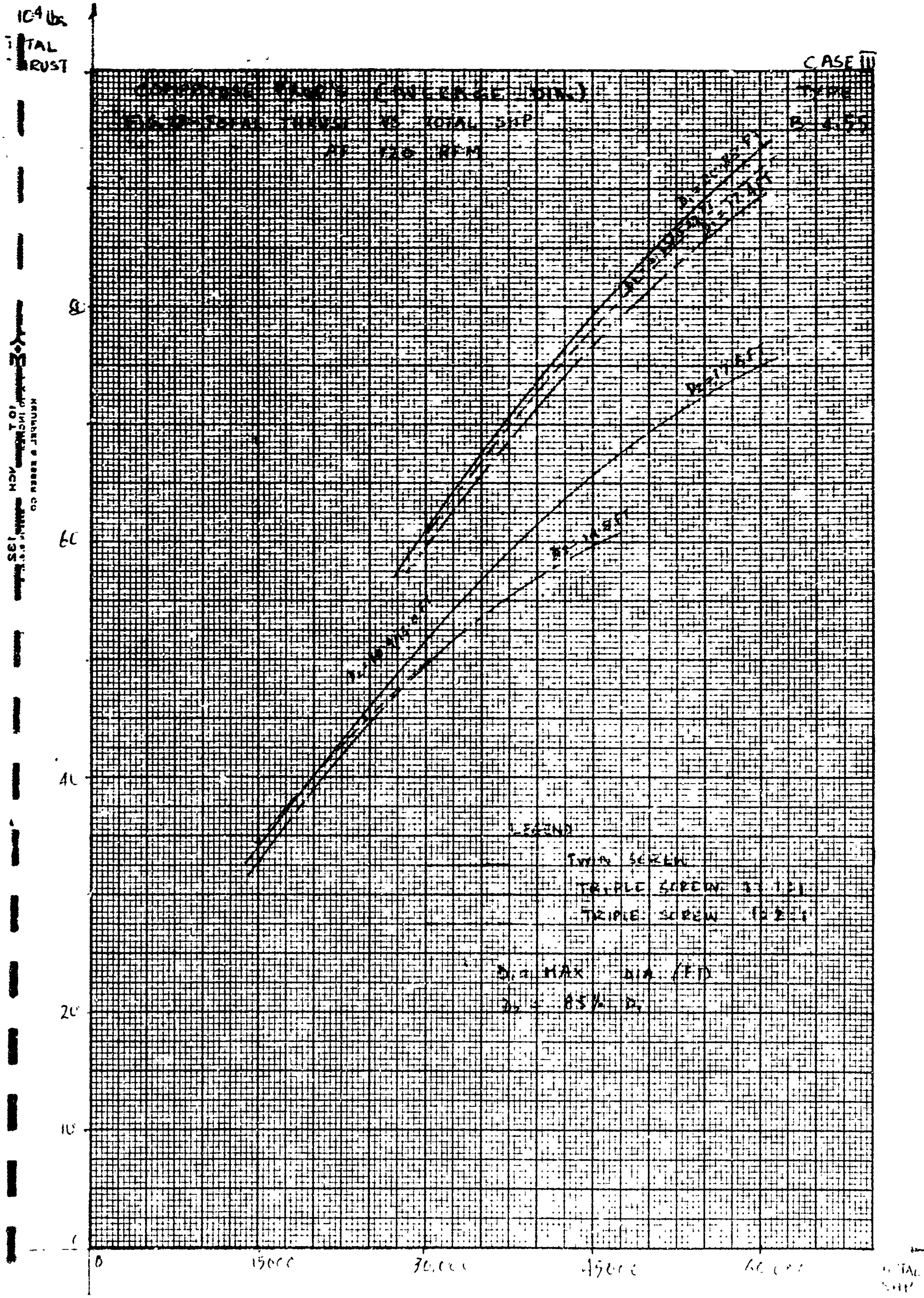

CASE III
TYPE
B 4.55
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW
15000
30,000
45000
80
60
40
20
10

FIG 74

CASE II

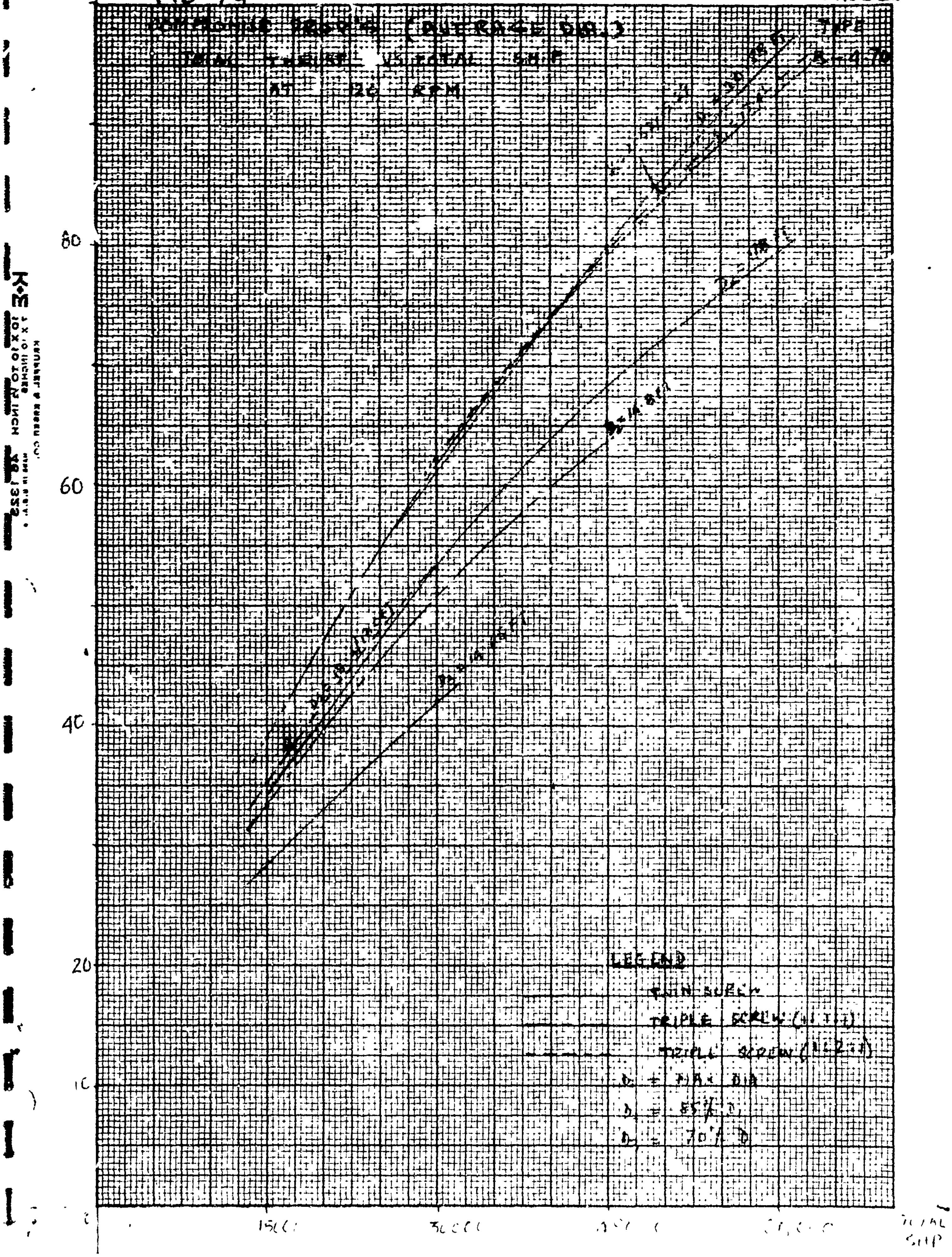
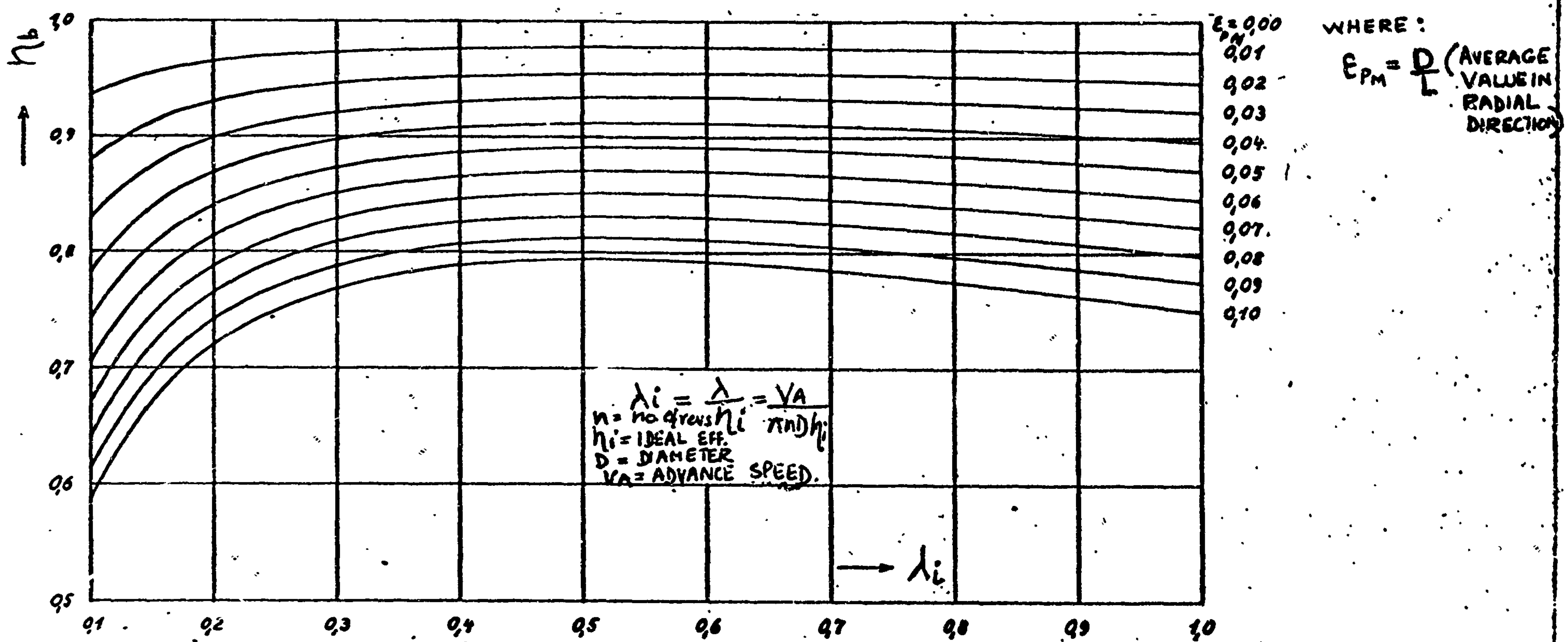


FIG. 75 BLADE EFFICIENCY η_b OF PROPELLER AS A FUNCTION OF MEAN DRAG-LIFT RATIO AND INDUCED ADVANCE NUMBER λ_i



THIS DIAGRAM WAS MODIFIED FROM A CHART OF THE TECHNICAL UNIVERSITY OF BERLIN

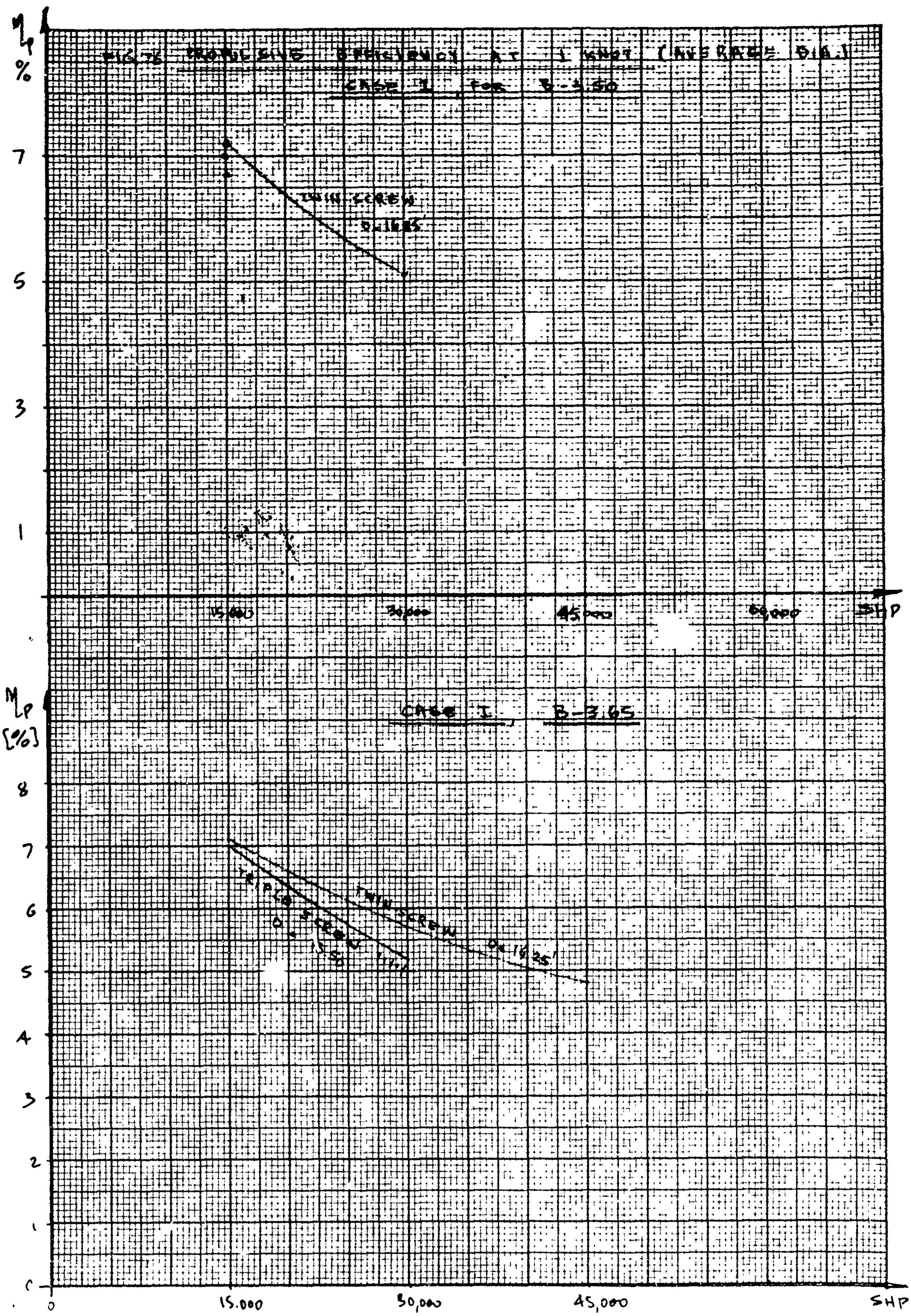
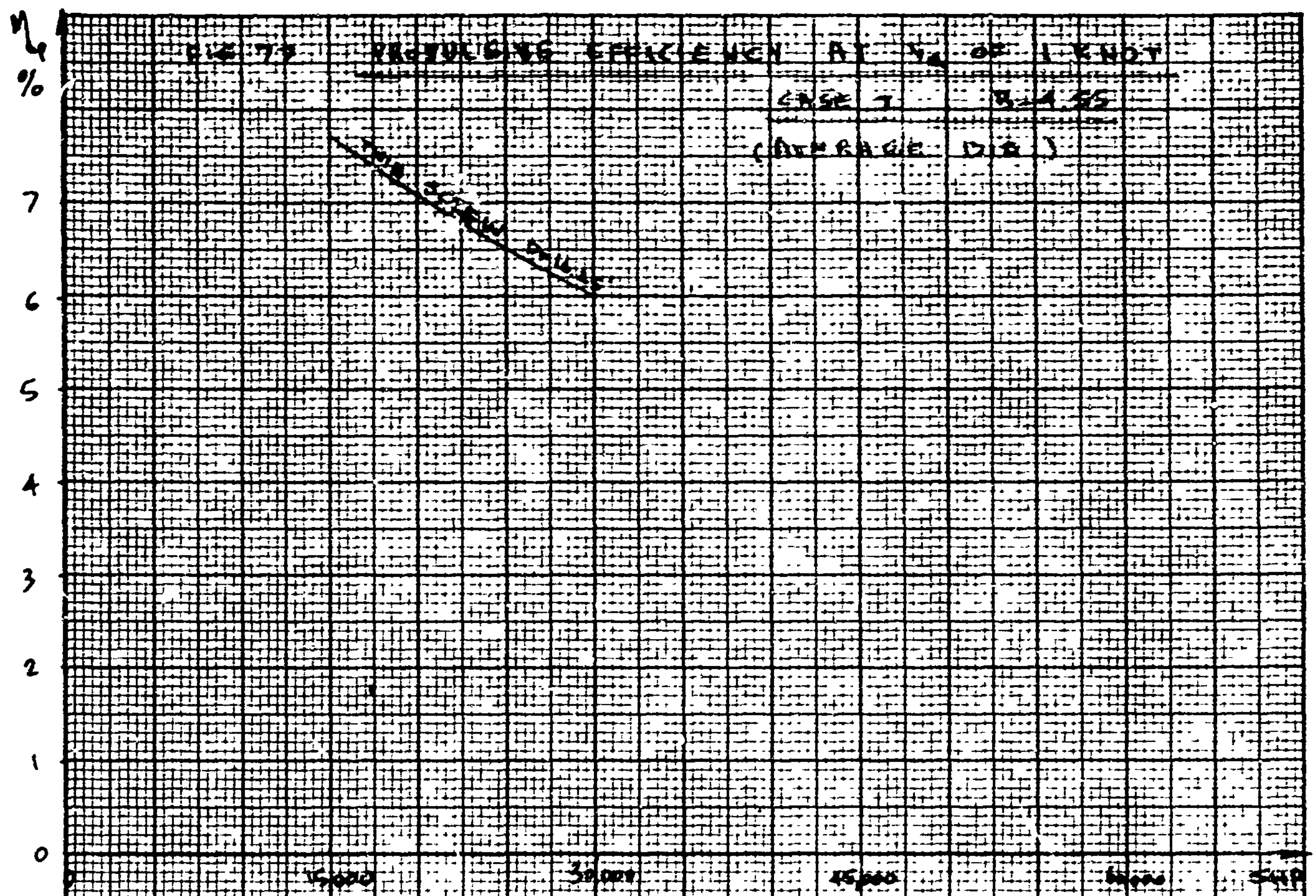
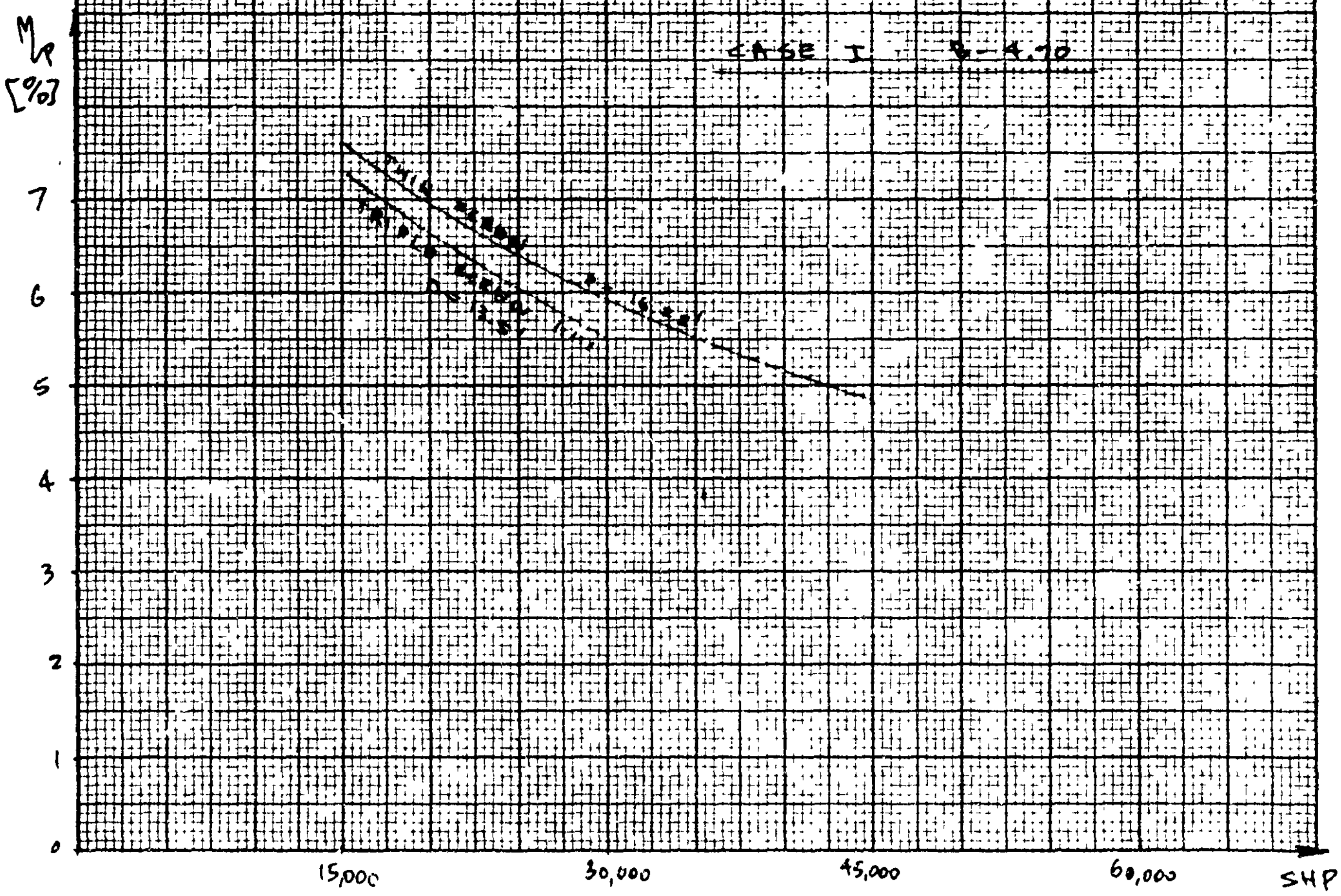
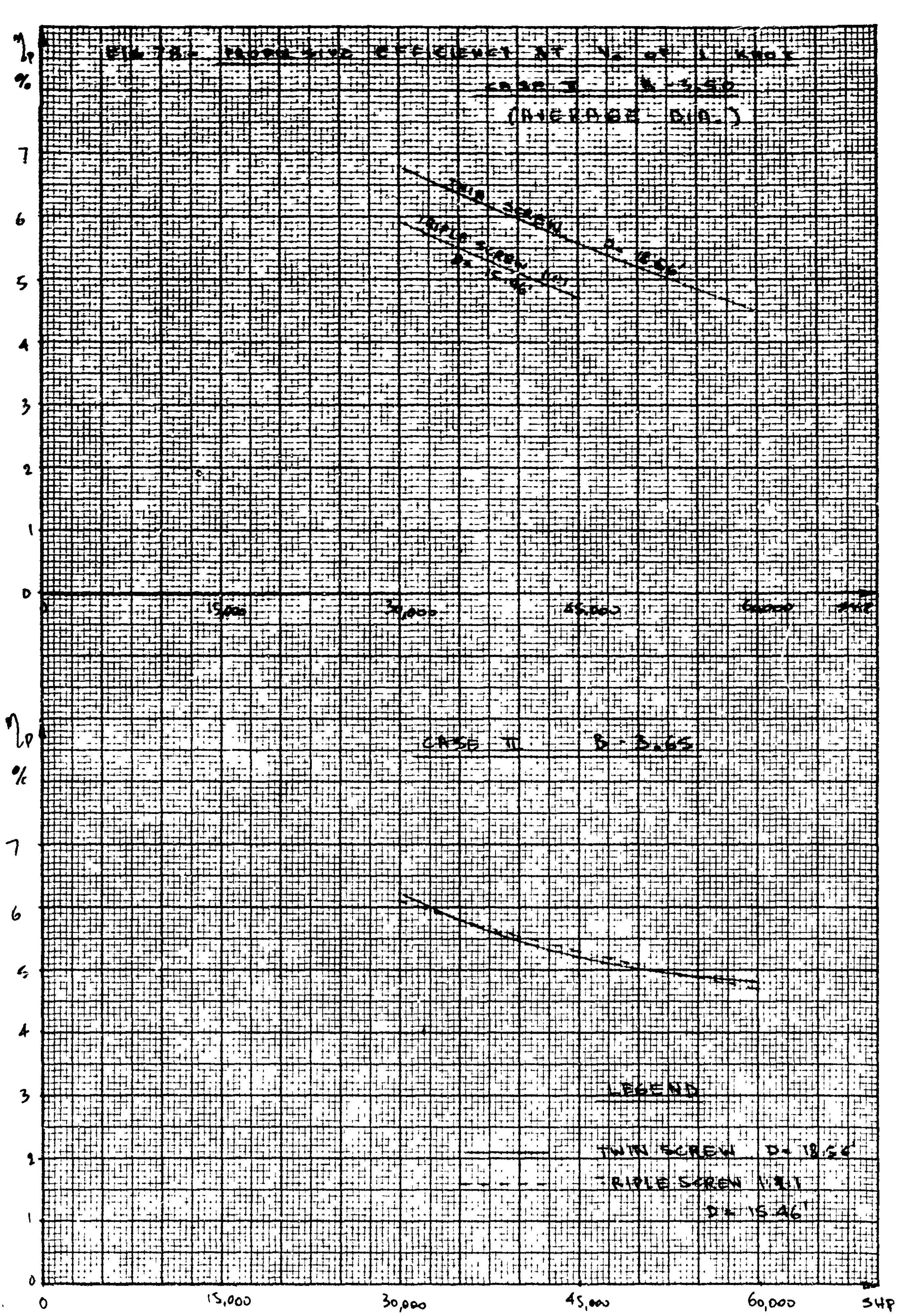


FIG. 76 PROPULSIVE EFFICIENCY AT 1 KNOT (AVERAGE DIA.)
CASE I, FOR B-3.50
η_p %
TWIN SCREW
D=16.25
15,000
30,000
45,000
60,000
SHP
CASE I, B-3.65
η_p [%]
TRIPLE SCREW
D=15.50
TWIN SCREW
D=16.25'
0
15,000
30,000
45,000
SHP


%
7
6
5
4
3
2
1
0
30,000
SHP


[%]
CASE I
7
6
5
4
3
2
1
0
15,000
30,000
45,000
60,000
SHP



(AVERAGE DIA.)
TWIN SCREW
TRIPLE SCREW
%
0
15,000
30,000
45,000
60,000
SHP
LEGEND
TWIN SCREW D= 18.56
TRIPLE SCREW
D= 15.46

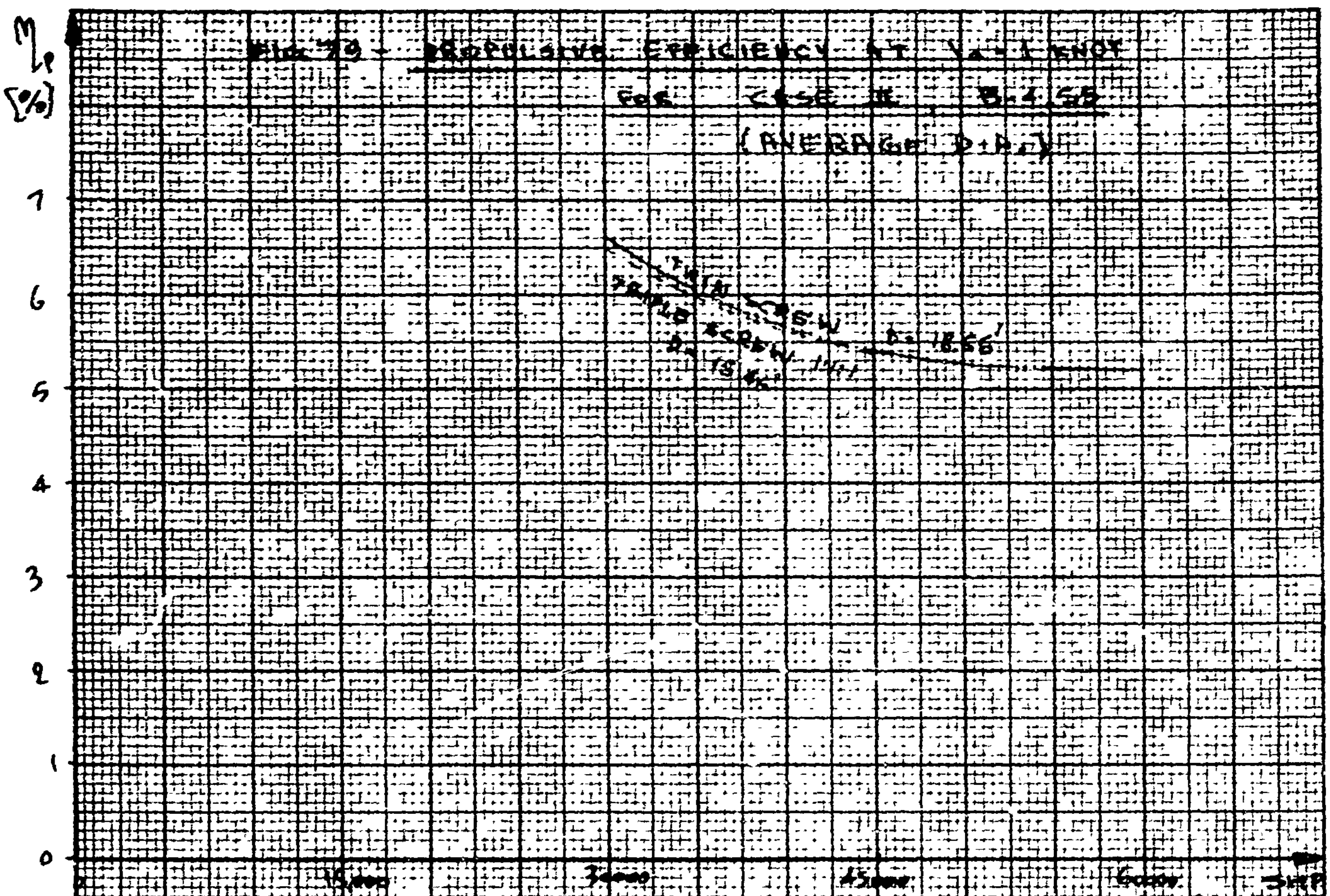
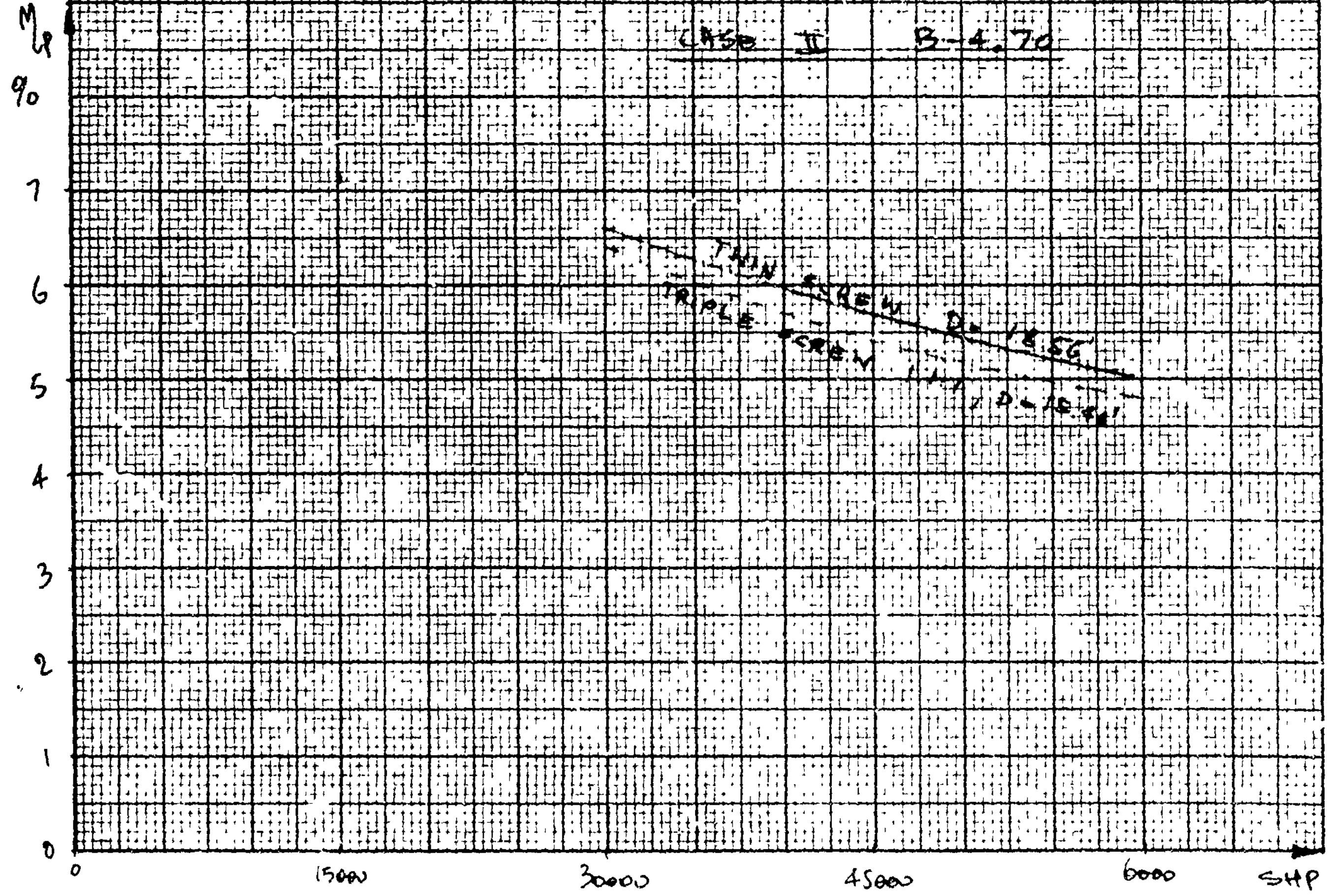


FIG. 79 - PROPULSIVE EFFICIENCY AT VA = 1 KNOT
FOR CASE II B-4.55
(AVERAGE D.P.)
ηp
[%]
TWIN SCREW D=18.56'
TRIPLE SCREW 1.41 D=15.46'
0
1
2
3
4
5
6
7
15000
30000
45000
60000
SHP


CASE II B-4.70
ηp
%
TWIN SCREW D=18.56
TRIPLE SCREW 1.41 D=15.46'
0
1
2
3
4
5
6
7
0
15000
30000
45000
60000
SHP

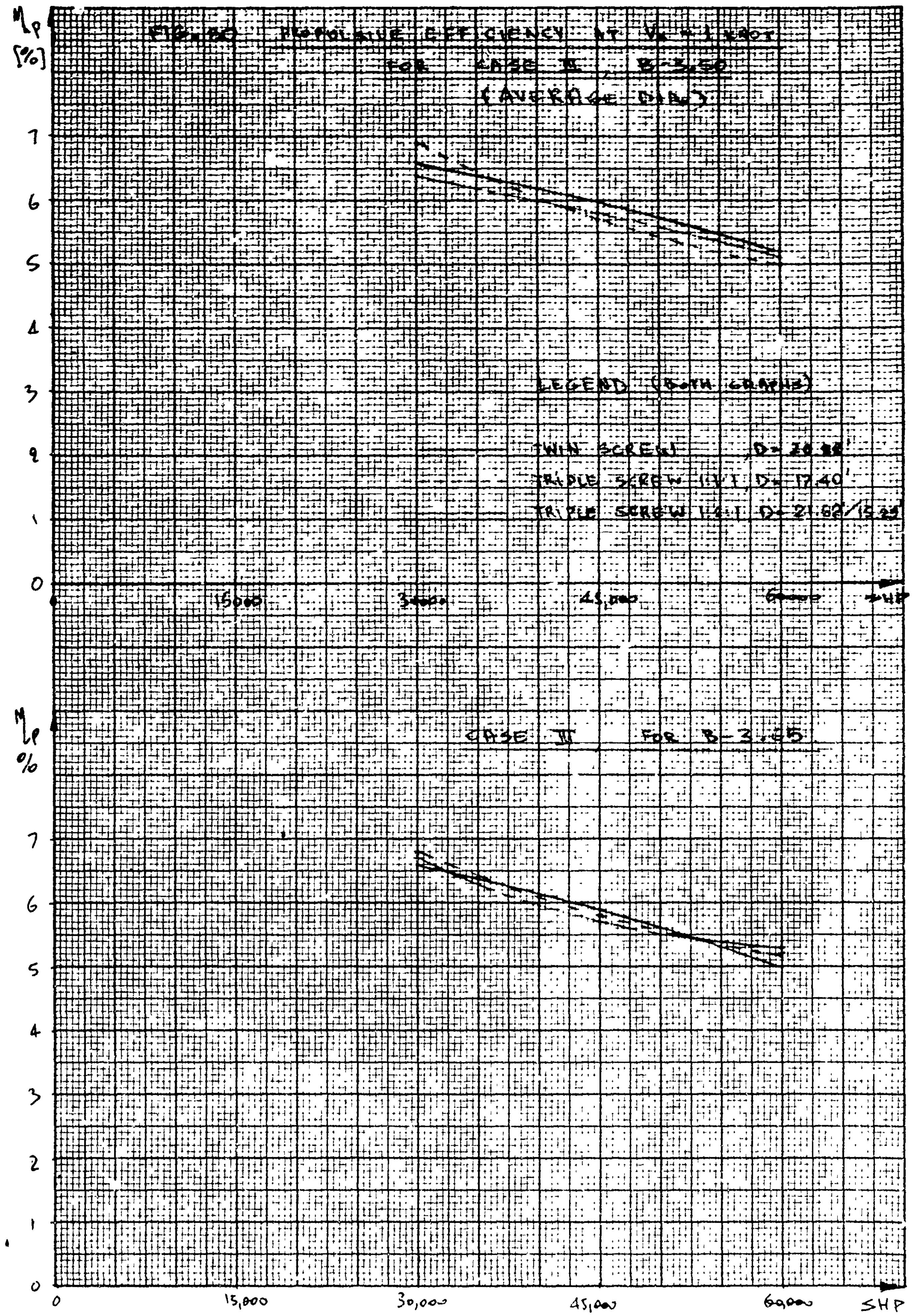
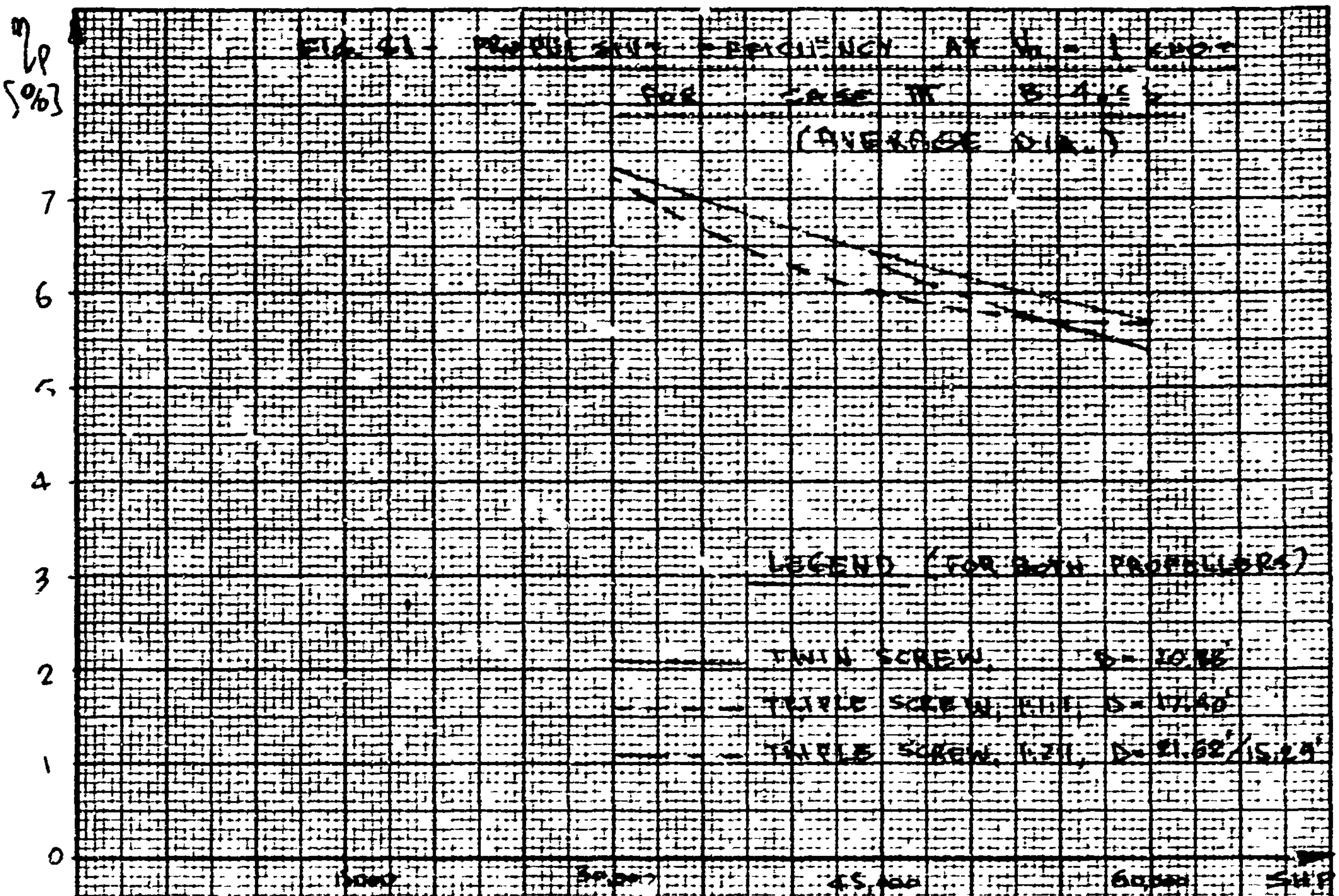
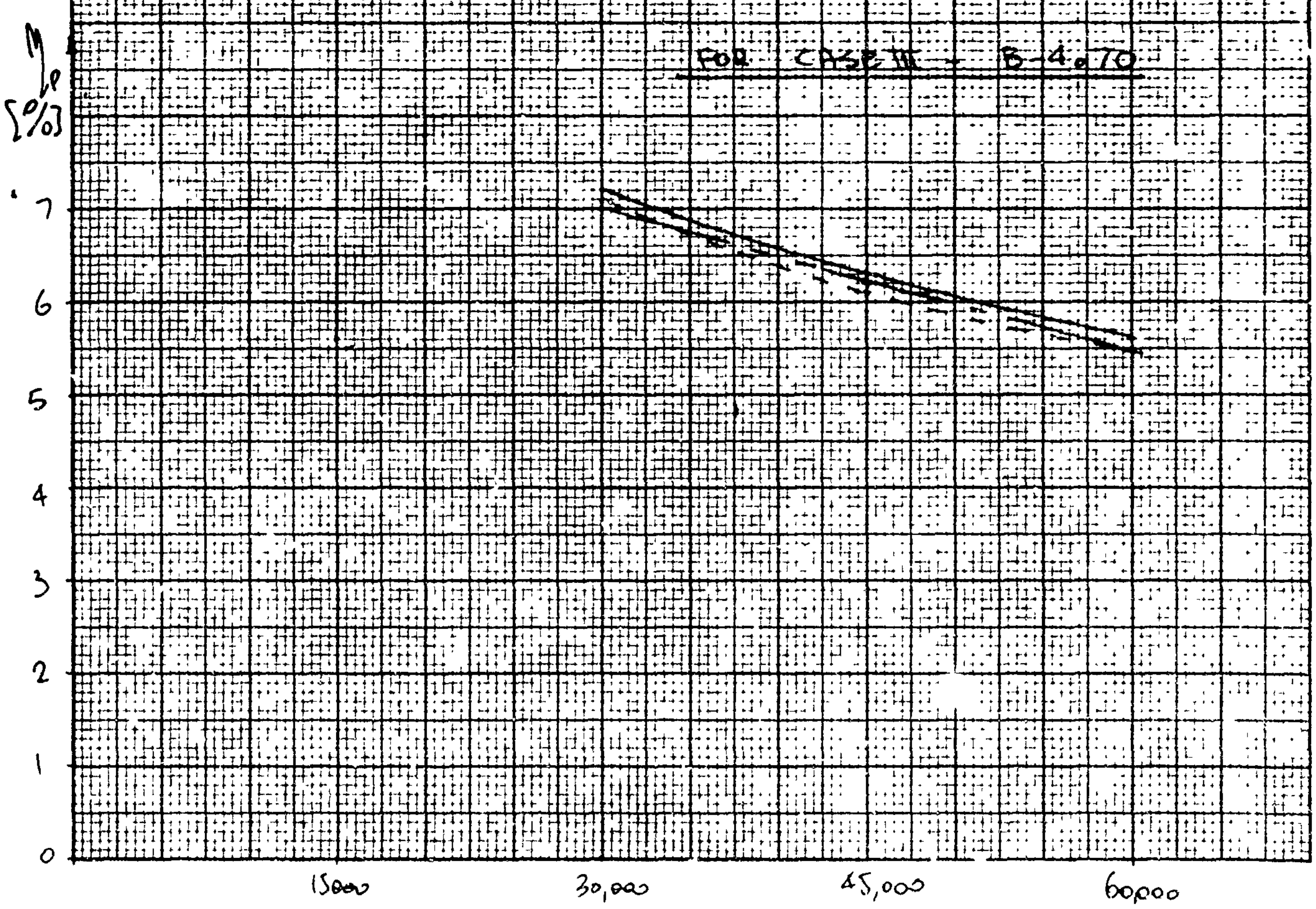


FIG. 80 PROPULSIVE EFFICIENCY AT Vs = 1 KNOT
FOR CASE II, B-3.50
(AVERAGE DIA.)
ηp [%]
LEGEND (BOTH GRAPHS)
TWIN SCREW, D = 20.88'
TRIPLE SCREW 1:1:1, D = 17.40'
TRIPLE SCREW 1:2:1, D = 21.82/15.25'
15000
30000
45,000
60000
SHP
CASE II FOR B-3.65
ηp %
0
15,000
30,000
45,000
60,000
SHP


(AVERAGE DIA.)
[%]
7
6
5
4
3
2
1
0
LEGEND (FOR BOTH PROPELLERS)
TWIN SCREW,
TRIPLE SCREW,
TRIPLE SCREW,
D=21.62'/15.29'
15000
30,000
45,000
60,000
SHP


FOR CASE III - B-4.70
[%]
7
6
5
4
3
2
1
0
15000
30,000
45,000
60,000

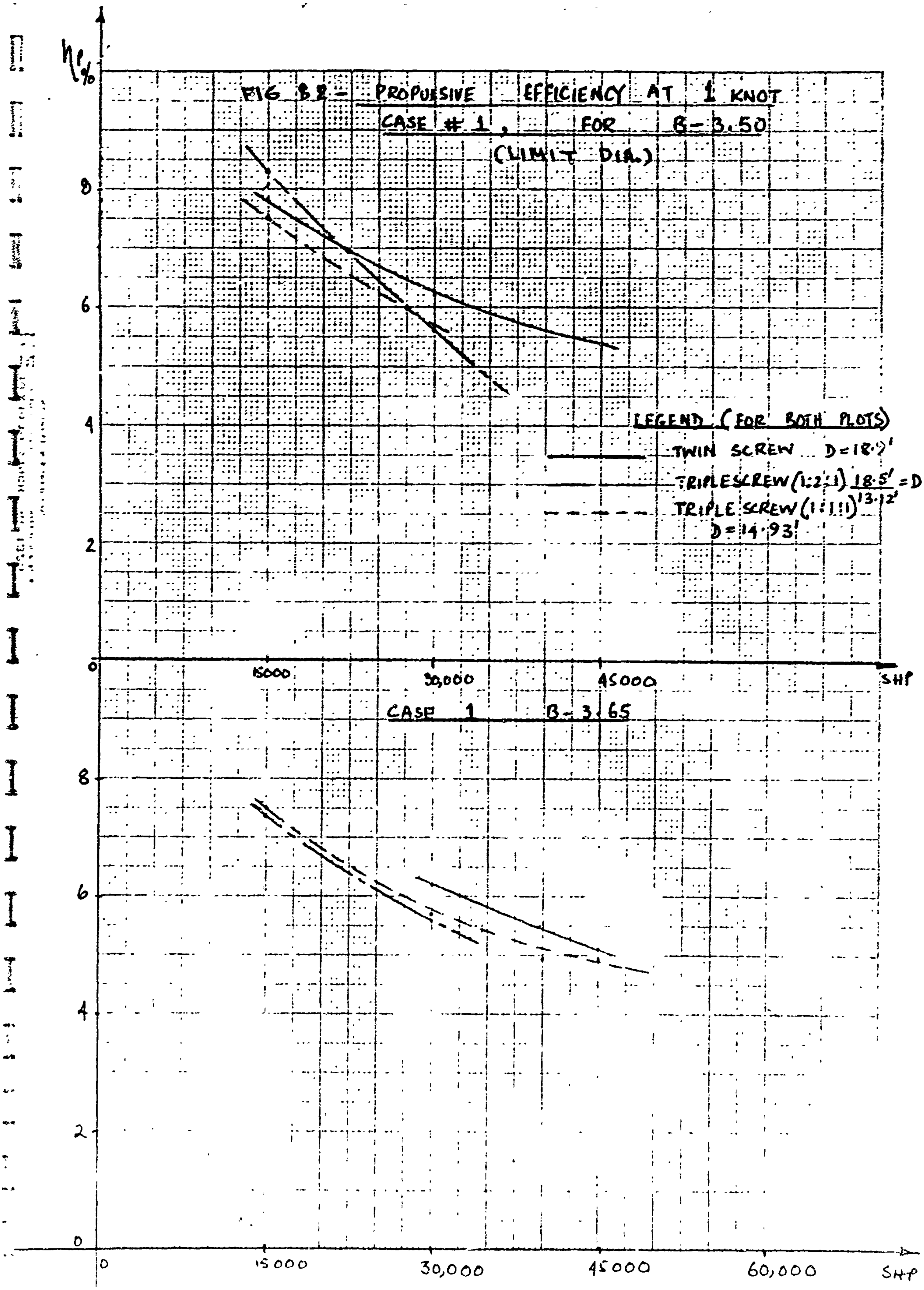


FIG B2 - PROPULSIVE EFFICIENCY AT 1 KNOT
CASE # 1, FOR B-3.50
(LIMIT DIA.)
ηp%
8
6
4
2
0
15000
30,000
45000
SHP
LEGEND (FOR BOTH PLOTS)
TWIN SCREW D=18.7'
TRIPLESCREW (1:2:1) 18.5'/13.12' = D
TRIPLE SCREW (1:1:1) D=14.93'
CASE 1 B-3.65
8
6
4
2
0
0
15000
30,000
45000
60,000
SHP

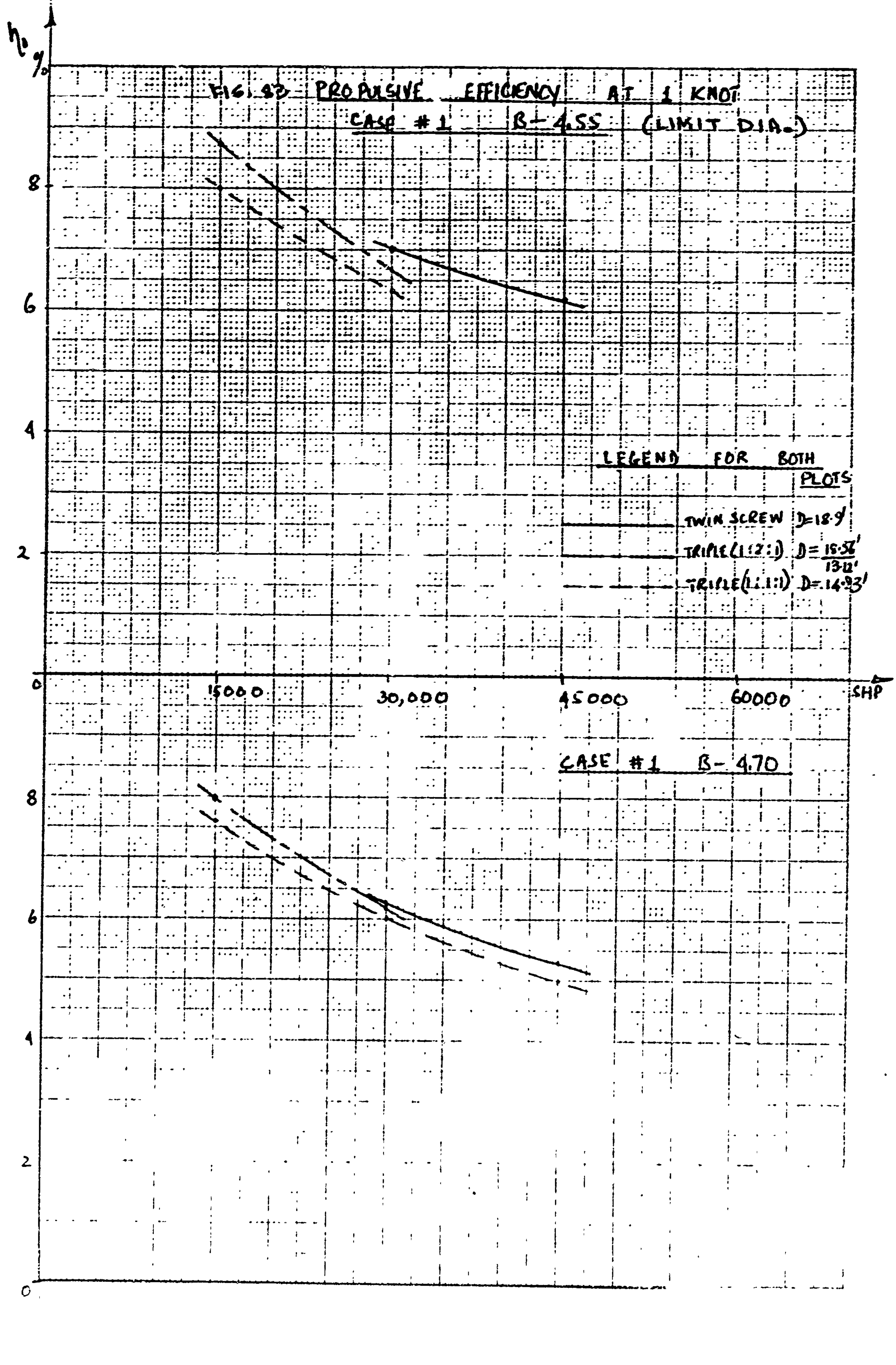


FIG. 83 PROPULSIVE EFFICIENCY AT 1 KNOT
CASE #1 B-4.55 (LIMIT DIA.)
η_0 %
8
6
4
2
0
15000
30,000
45000
60000
SHP
LEGEND FOR BOTH PLOTS
TWIN SCREW D=18.9'
TRIPLE (1:2:1) D=15.56'/13.12'
TRIPLE (1:1:1) D=14.93'
CASE #1 B-4.70

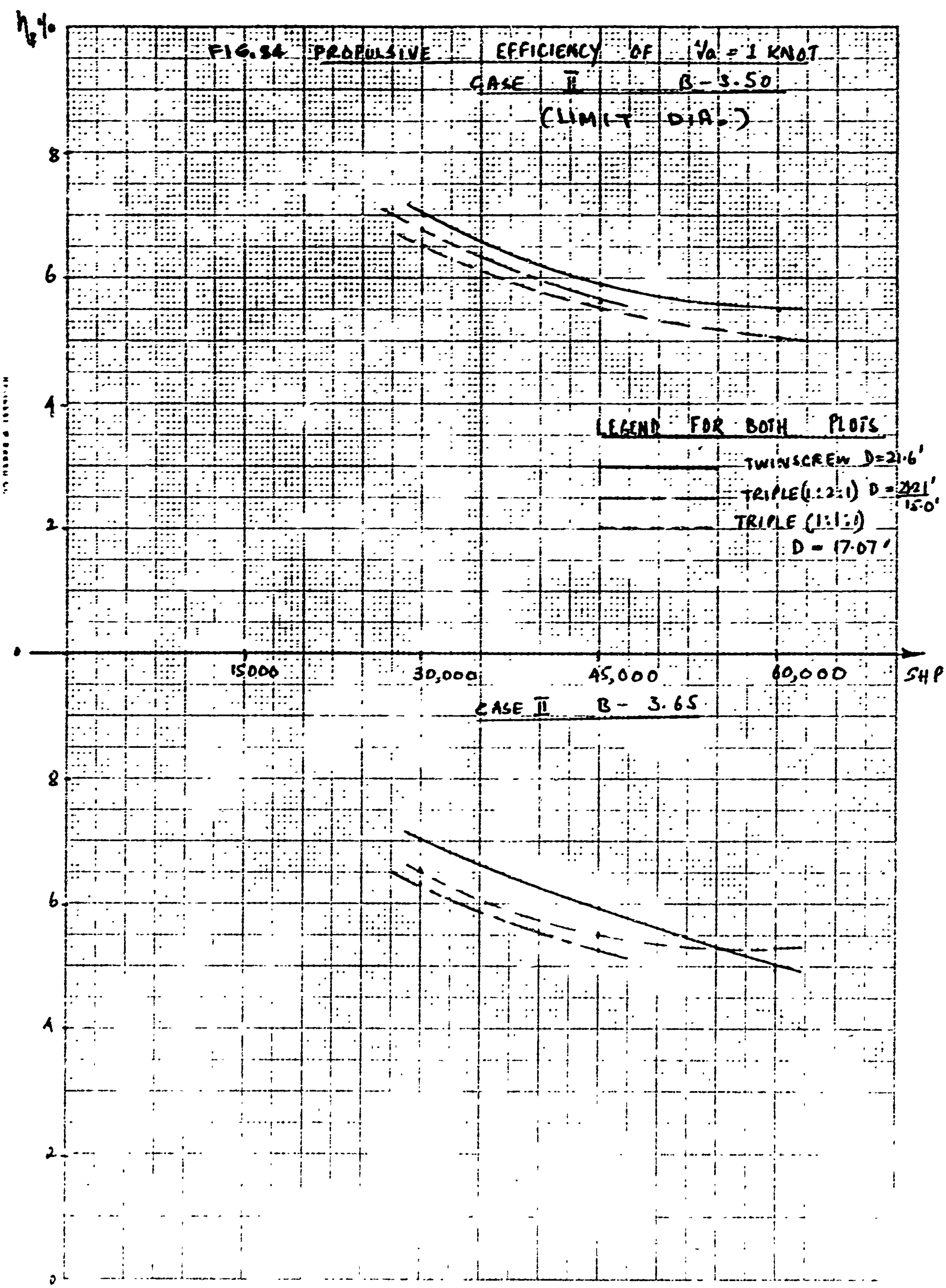


FIG. 34 PROPULSIVE EFFICIENCY OF Va = 1 KNOT
CASE II B - 3.50
(LIMIT DIA.)
η %
8
6
4
2
0
LEGEND FOR BOTH PLOTS
TWINSCREW D=21.6'
TRIPLE (1:2:1) D = 22.1' / 15.0'
TRIPLE (1:1:1) D = 17.07'
15000
30,000
45,000
60,000
SHP
CASE II B - 3.65

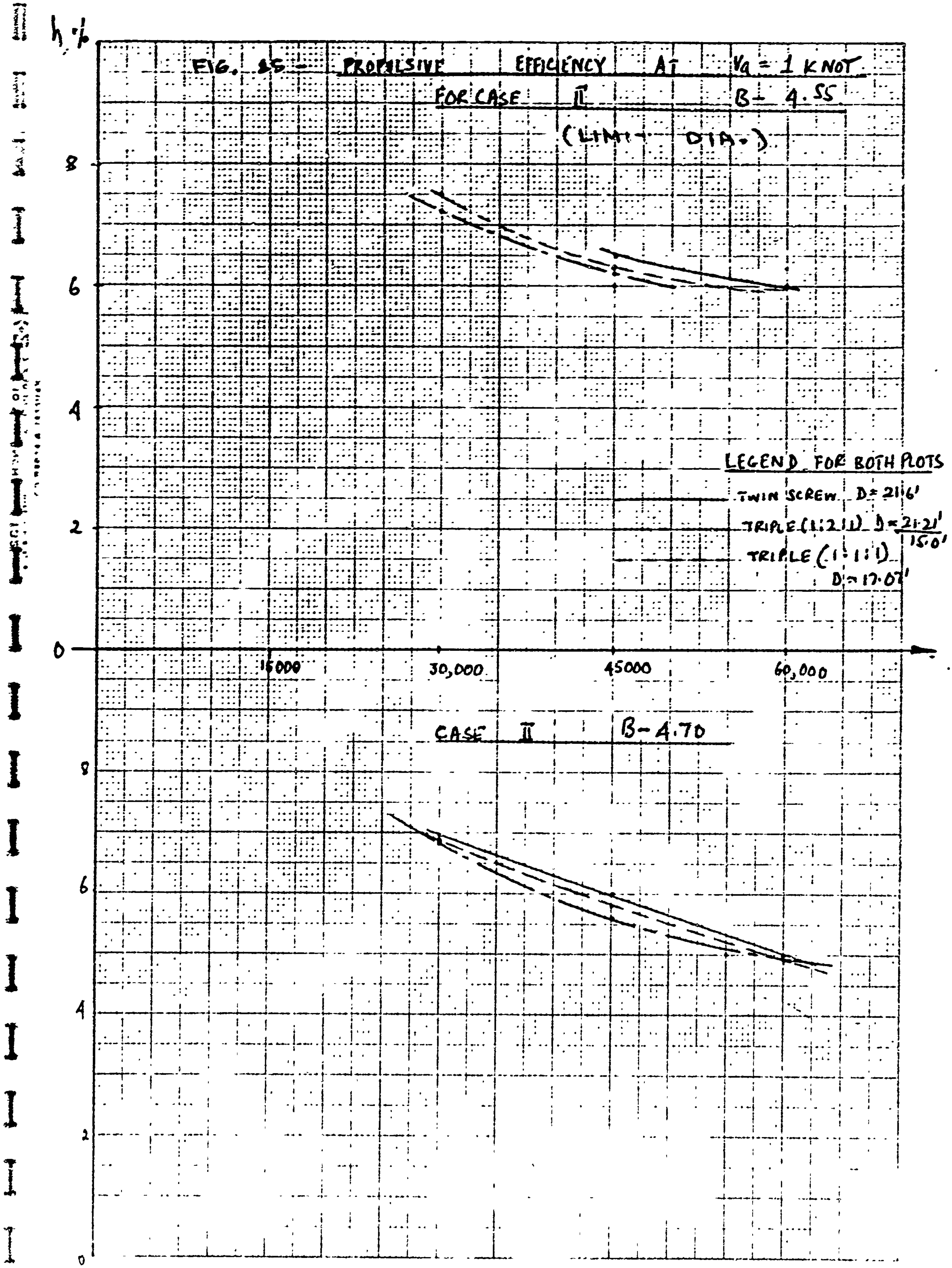


FIG. 85 – PROPULSIVE EFFICIENCY AT V_a = 1 KNOT
FOR CASE II B – 4.55
(LIMIT DIA.)
η %
8
6
4
2
0
15000
30,000
45000
60,000
LEGEND FOR BOTH PLOTS
TWIN SCREW D = 21.6'
TRIPLE (1:2:1) D = 21.21' / 15.0'
TRIPLE (1:1:1) D = 17.07'
CASE II B – 4.70
8
6
4
2
0

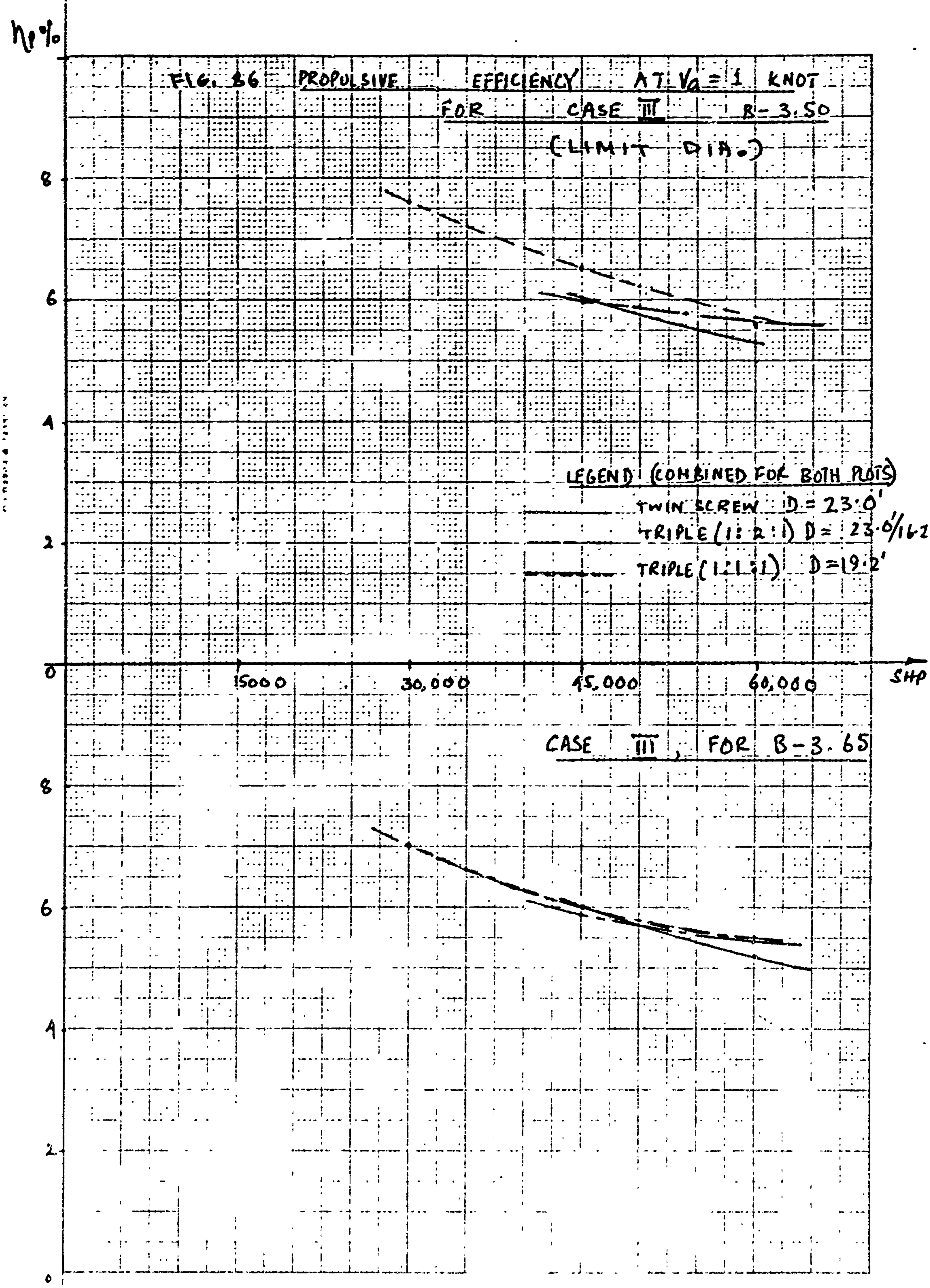
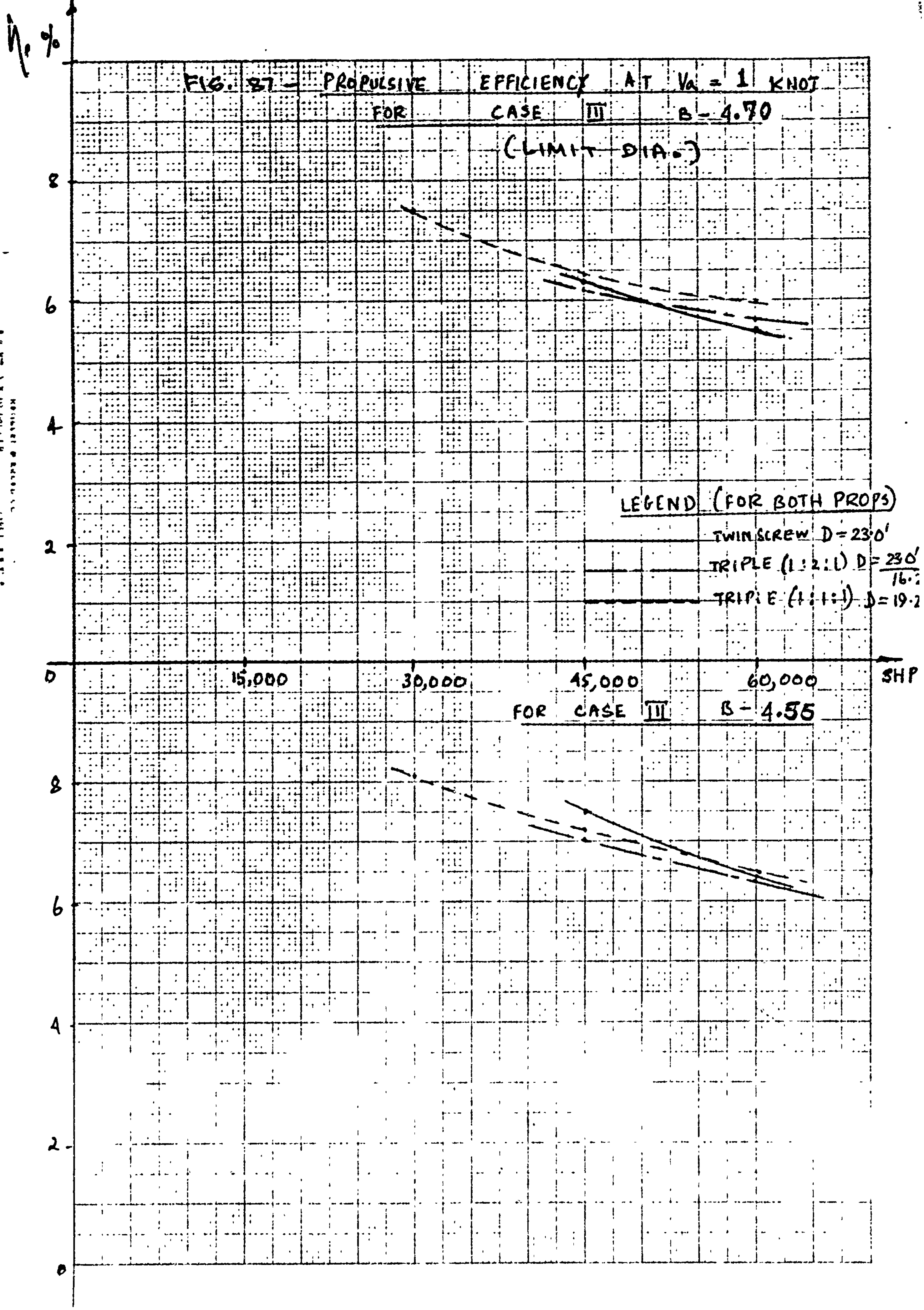
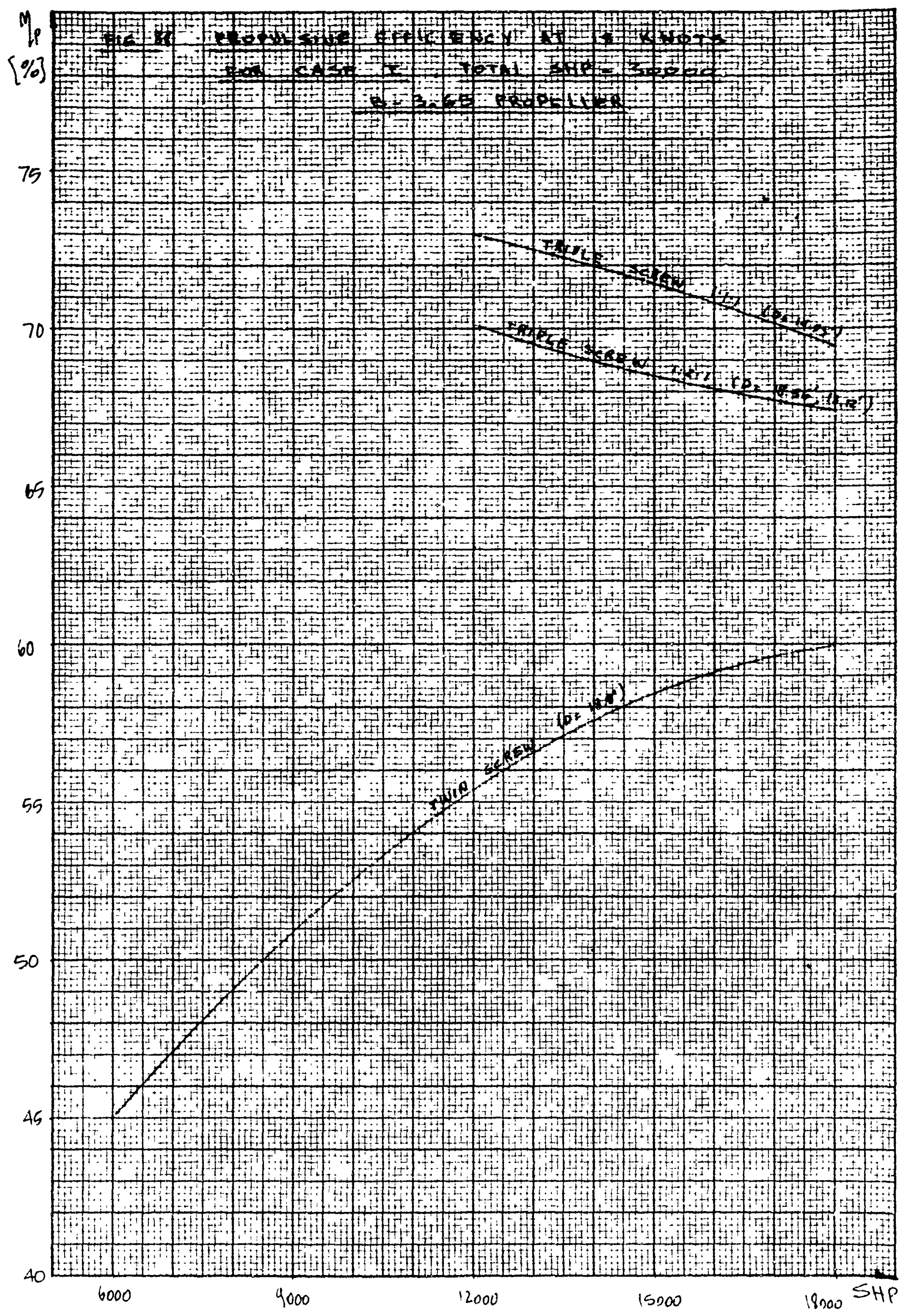

ηp%
FIG. 36 PROPULSIVE EFFICIENCY AT Va = 1 KNOT
FOR CASE III B-3.50
(LIMIT DIA.)
8
6
4
2
0
LEGEND (COMBINED FOR BOTH PLOTS)
TWIN SCREW D = 23·0'
TRIPLE (1:2:1) D = 23·0'/16·2
TRIPLE (1:1:1) D = 19·2'
15000
30,000
45,000
60,000
SHP
CASE III, FOR B-3.65
8
6
4
2
0

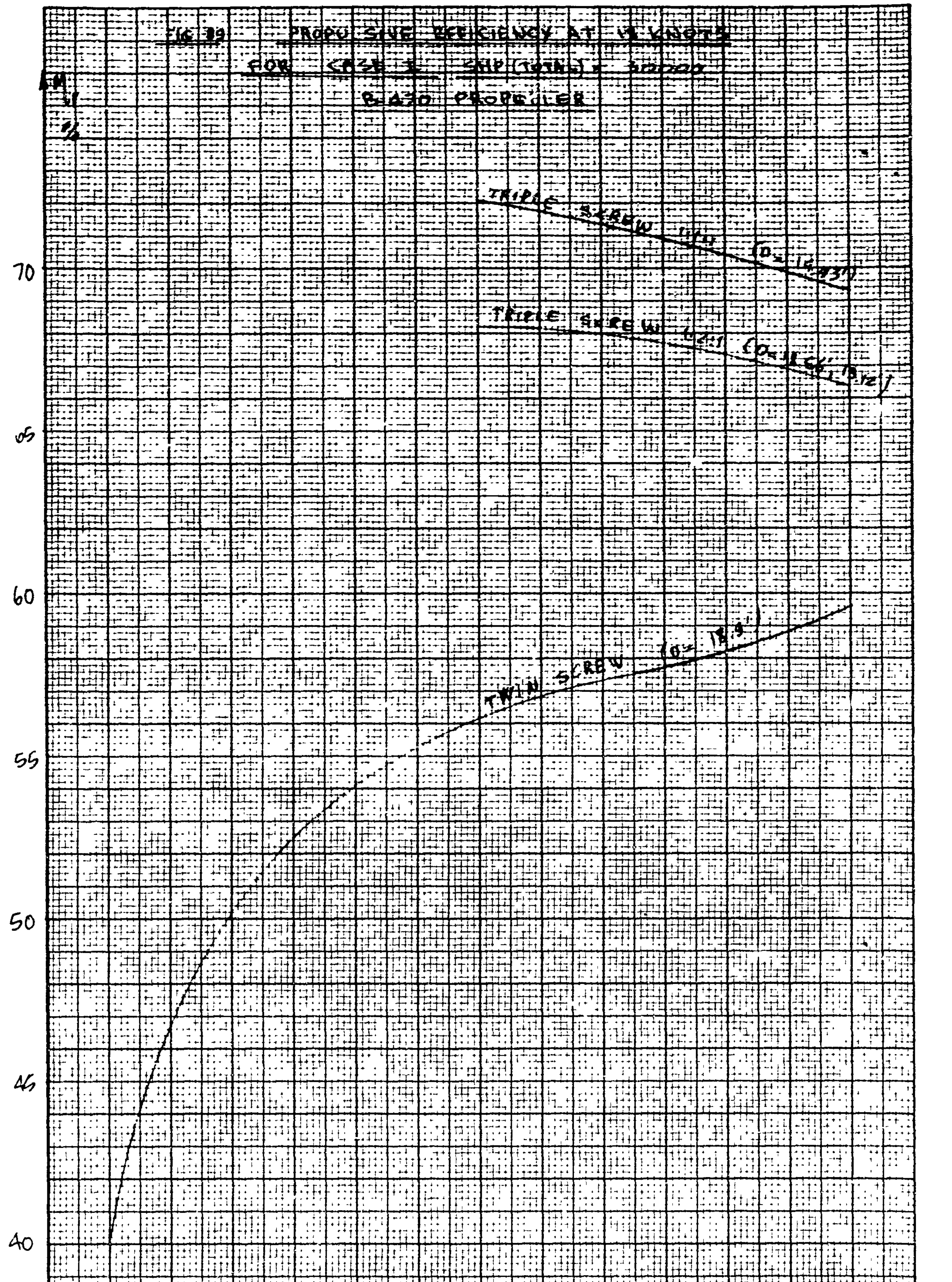
FIG. 37 — PROPULSIVE EFFICIENCY AT V_a = 1 KNOT

FOR CASE III B - 4.70

(LIMIT DIA.)




PROPULSIVE EFFICIENCY AT
KNOTS
FOR CASE I. TOTAL SHP = 30000
B-3.65 PROPELLER
η_P [%]
75
70
65
60
55
50
45
40
TRIPLE SCREW (1:1)
TRIPLE SCREW 1:2:1
TWIN SCREW
6000
9000
12000
15000
18000
SHP


TRIPLE SCREW
TRIPLE SCREW
TWIN SCREW
70
65
60
55
50
45
40
6000
9000
12,000
15,000
18,000
SHP

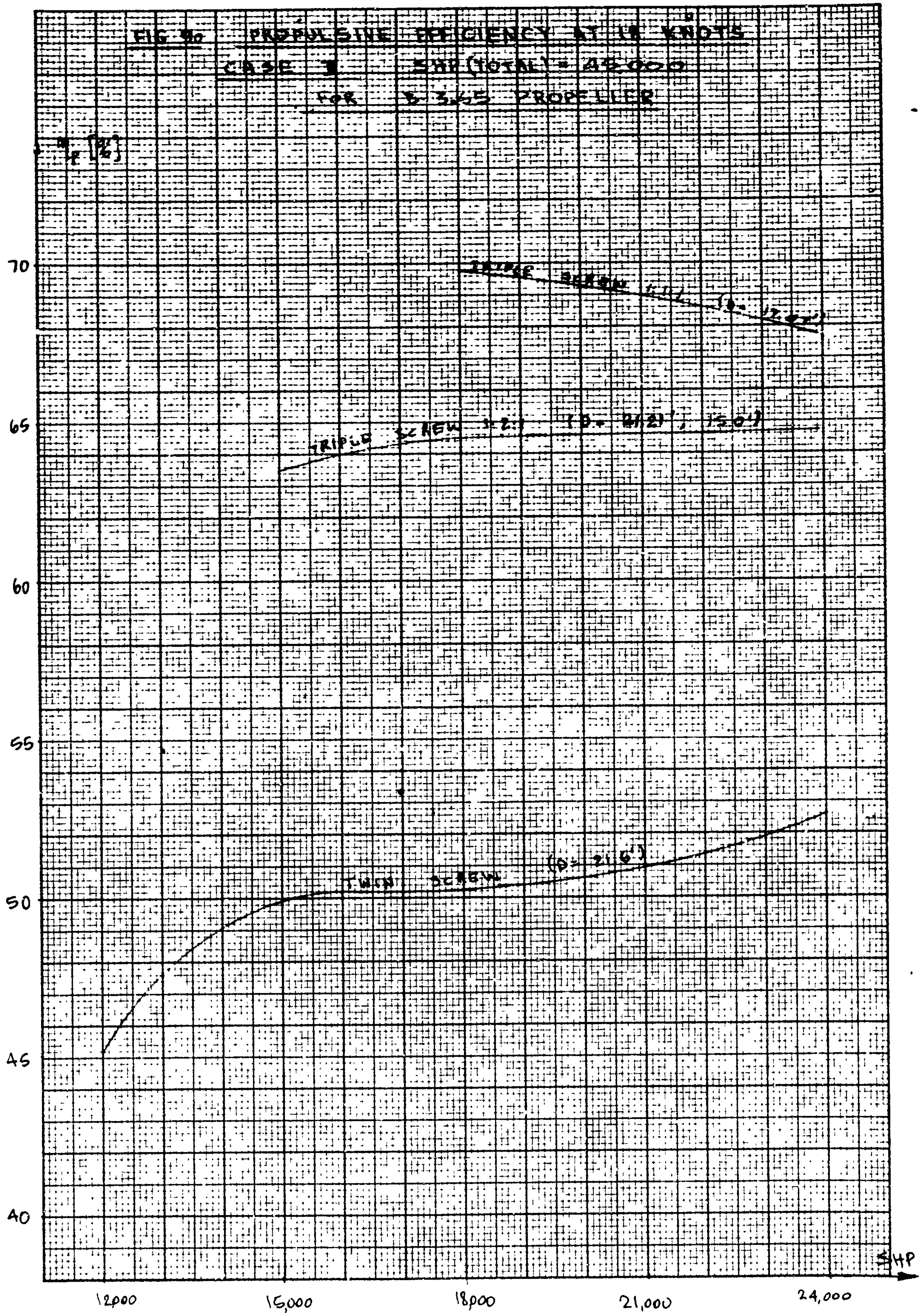


FIG 90 PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE II SHP (TOTAL) = 48,000
FOR B 3.65 PROPELLER
70
65
60
55
50
45
40
TRIPLE SCREW
TRIPLE SCREW
TWIN SCREW
12,000
15,000
18,000
21,000
24,000
SHP

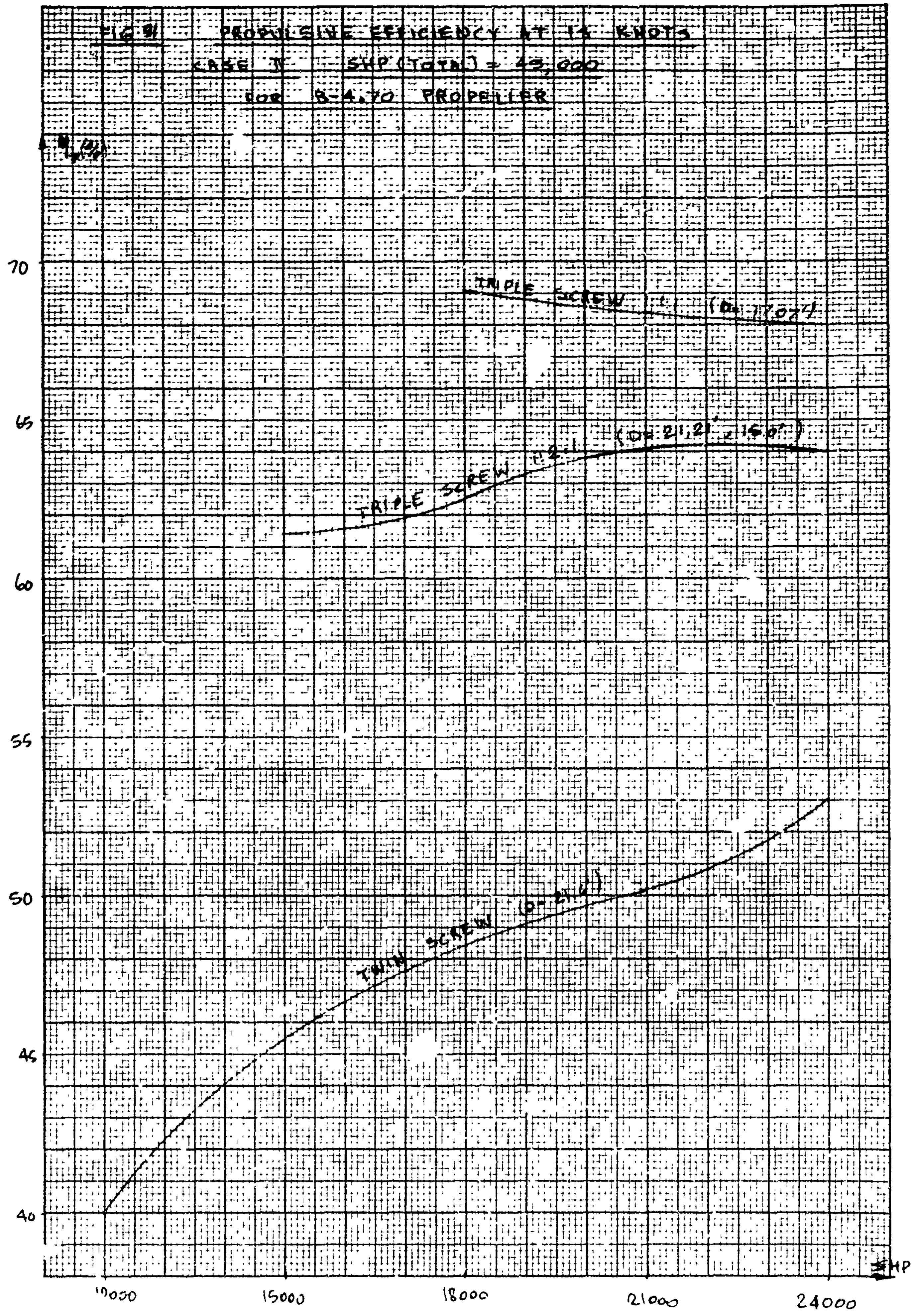


FIG 91 PROPULSIVE EFFICIENCY AT 14 KNOTS
CASE IV SHP (TOTAL) = 45,000
FOR B-4.70 PROPELLER
70
65
60
55
50
45
40
TRIPLE SCREW
TRIPLE SCREW
TWIN SCREW
10000
15000
18000
21000
24000
SHP

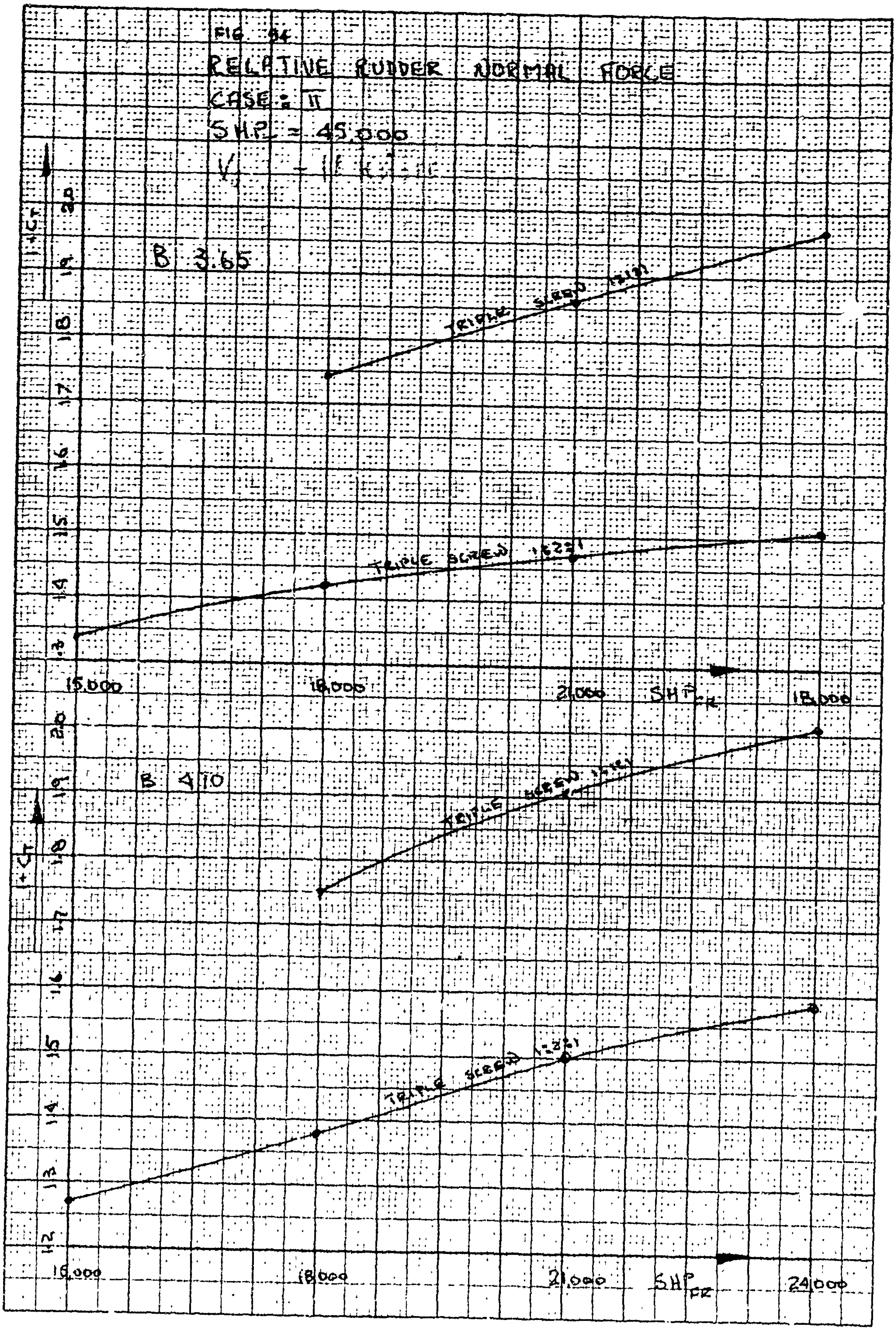


FIG. 94
RELATIVE RUDDER NORMAL FORCE
CASE: II
SHP = 45,000
B 3.65
TRIPLE SCREW
TRIPLE SCREW 1.221
15,000
18,000
21,000
SHP_{FR}
B 4.10
TRIPLE SCREW
TRIPLE SCREW 1.221
15,000
18,000
21,000
SHP_{FR}
24,000

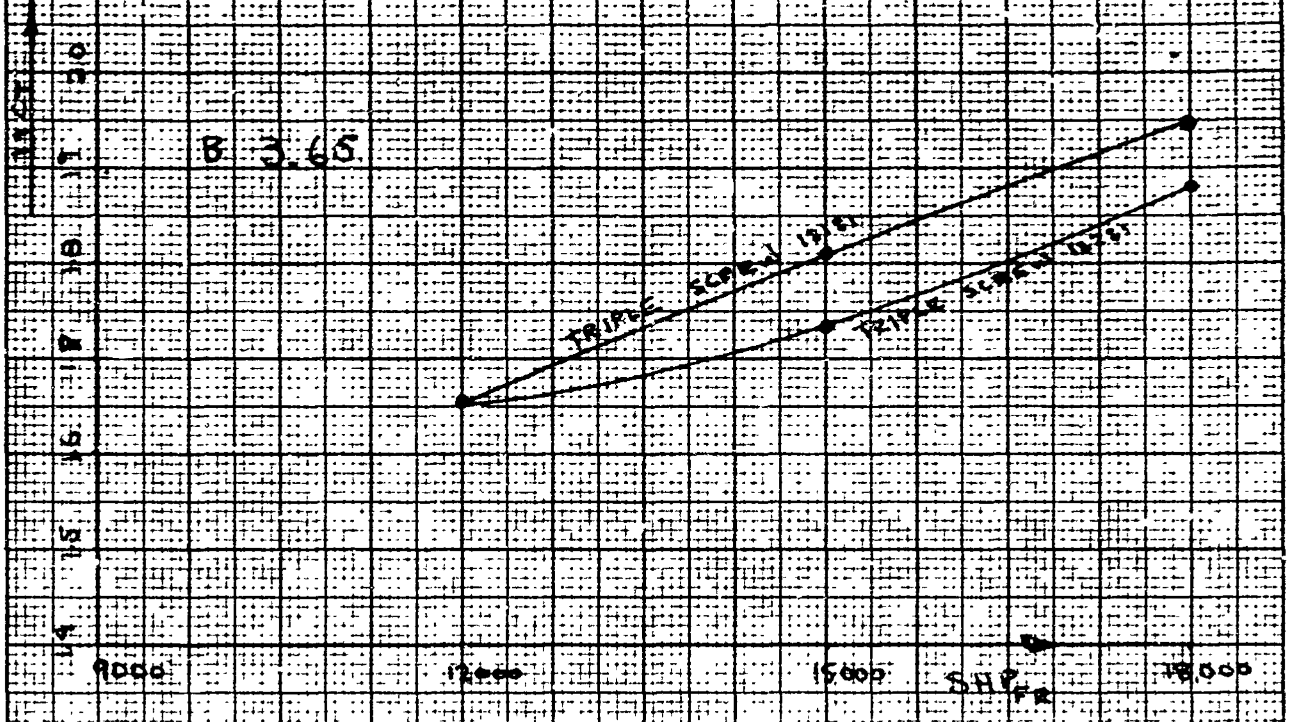
FIG. 35

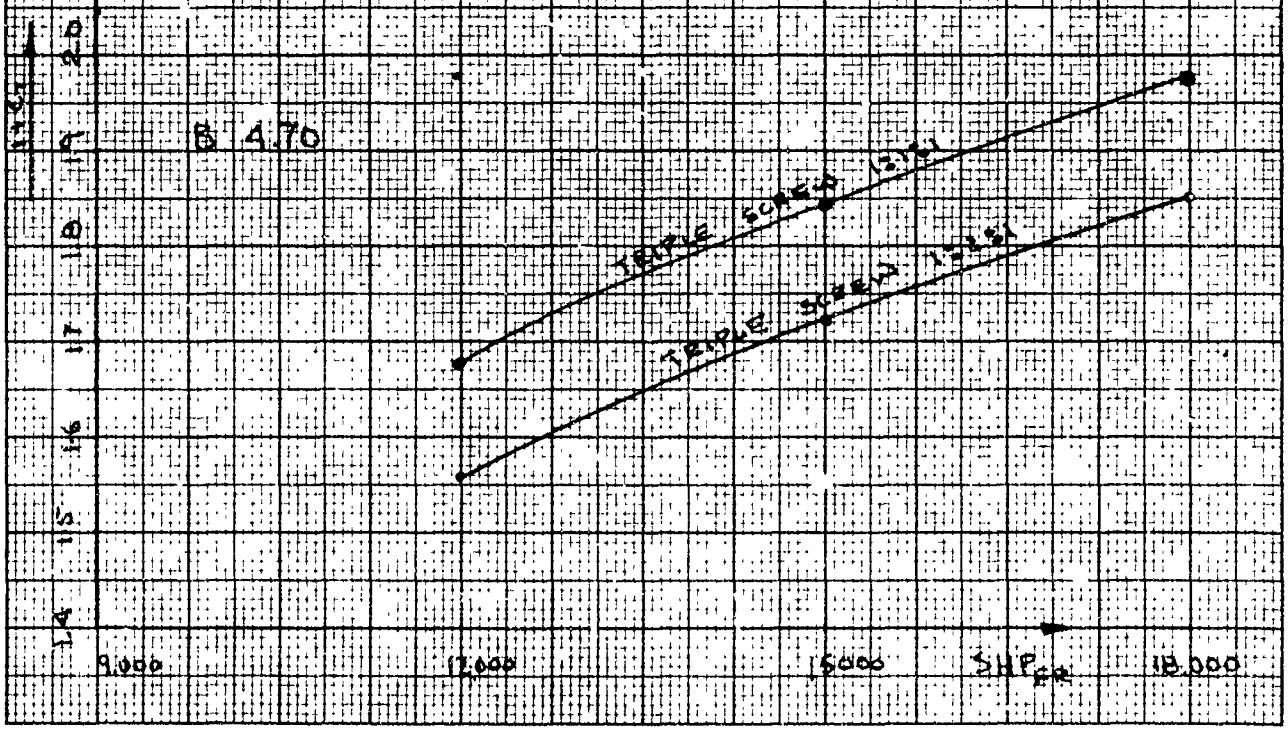
RELATIVE RUDDER NORMAL FORCE

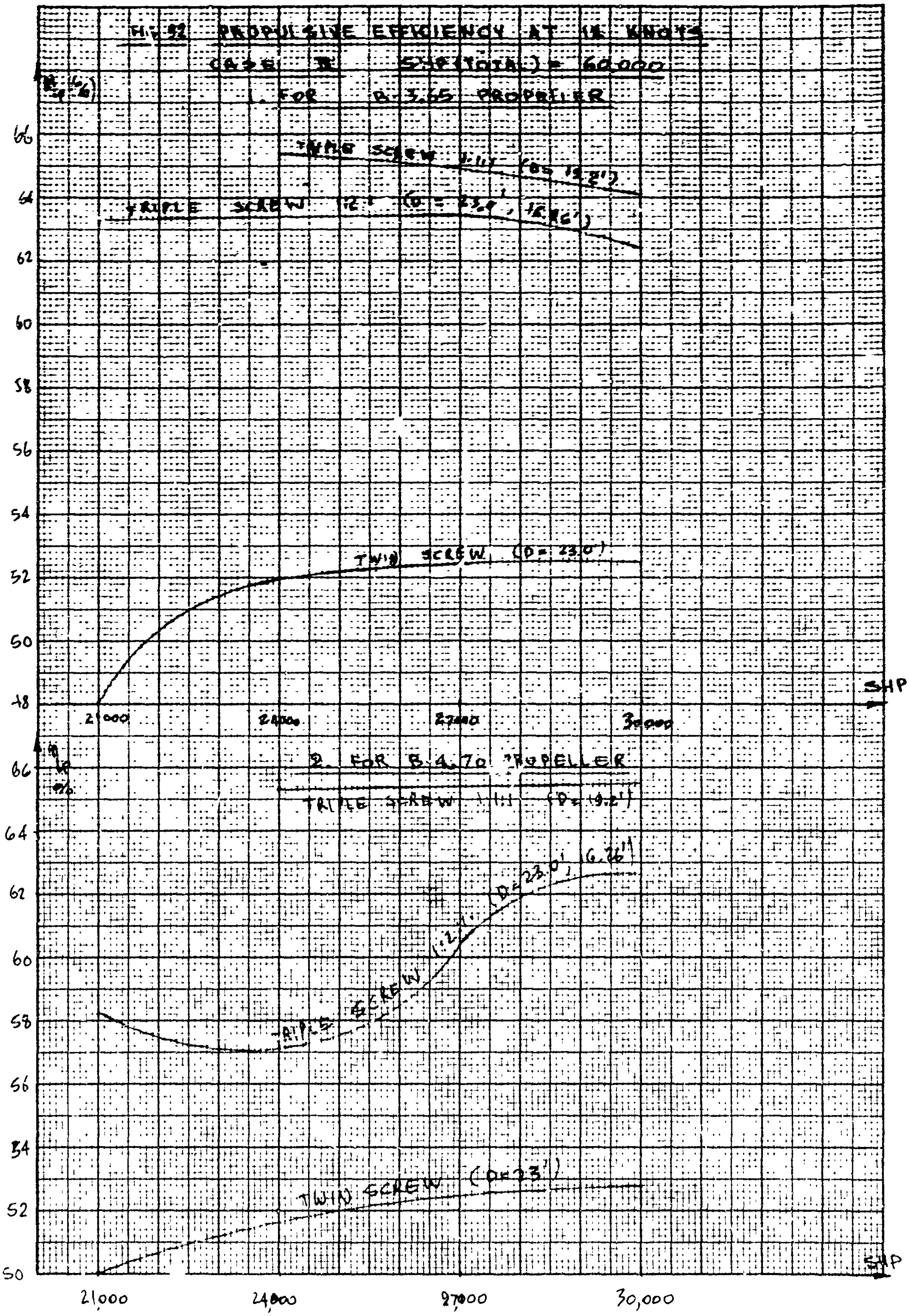
CASE: I

SHP = 30,000

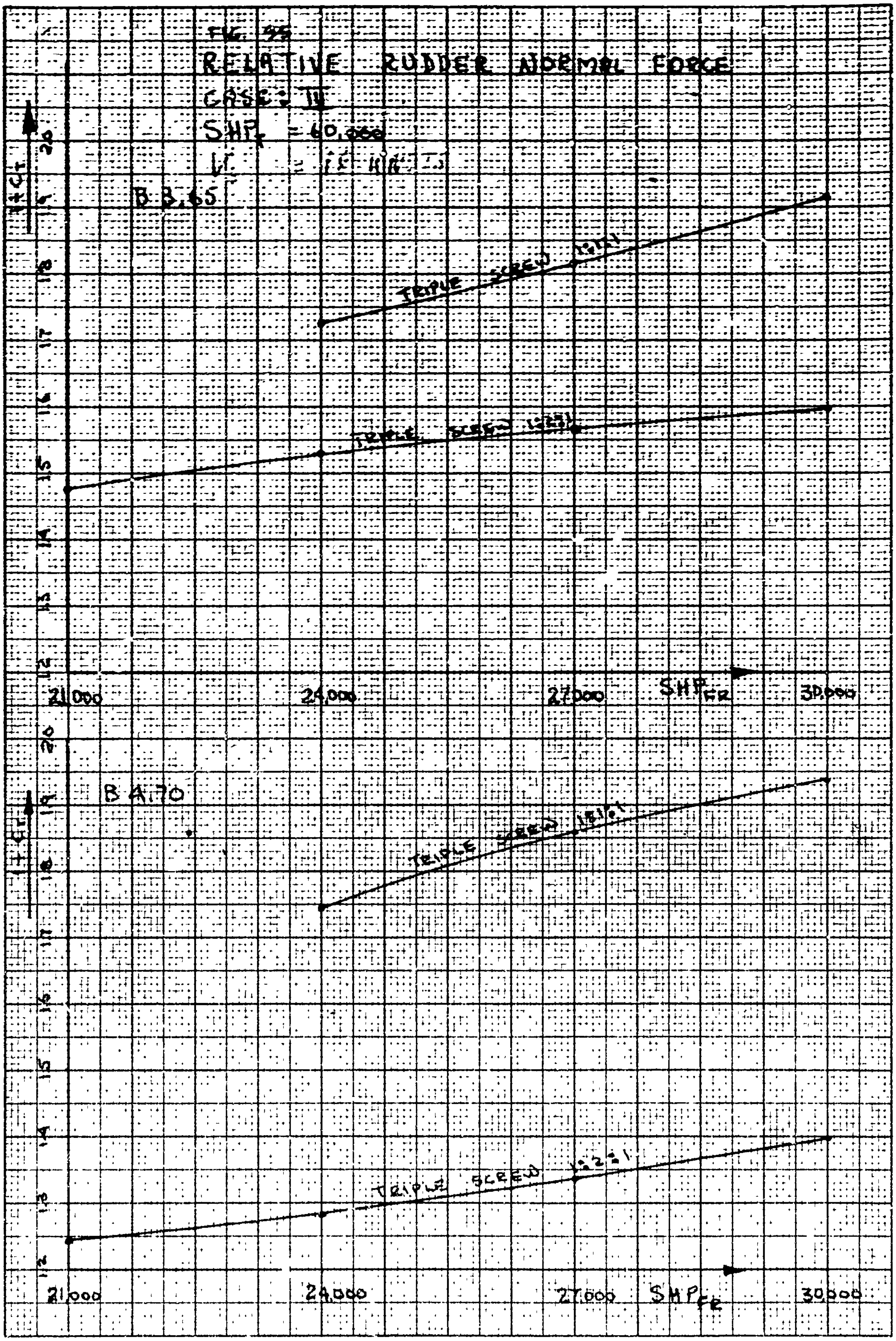
V_S = 18 KNOTS



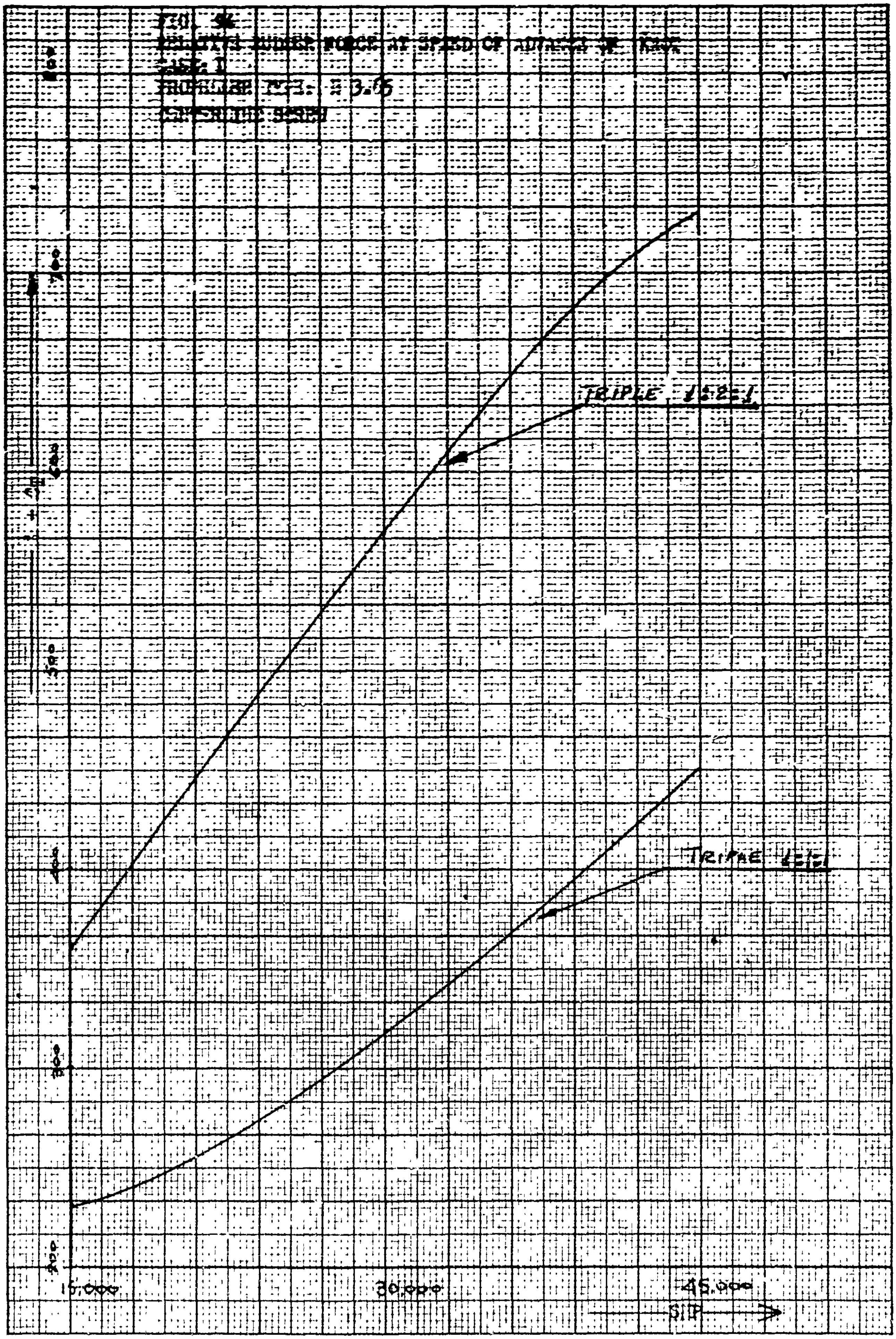




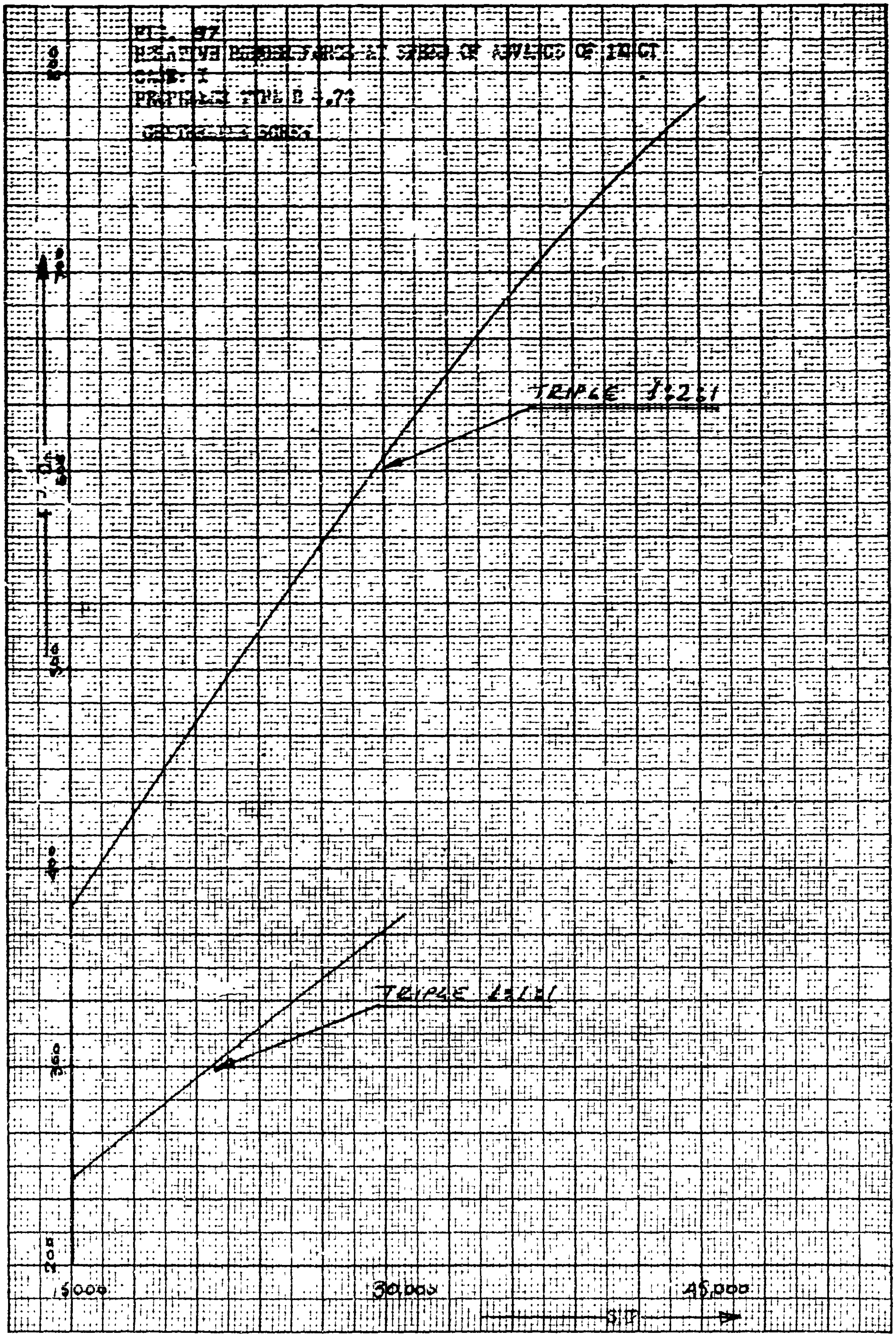
PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE II SHP (TOTAL) = 60,000
1. FOR B.3.65 PROPELLER
TWIN SCREW
TRIPLE SCREW
TWIN SCREW (D = 23.0')
66
64
62
60
58
56
54
52
50
48
21000
24000
27000
30000
SHP
2. FOR B.4.70 PROPELLER
TRIPLE SCREW
TRIPLE SCREW
D = 23.0'
TWIN SCREW (D = 23')
66
64
62
60
58
56
54
52
50
21,000
24,000
27,000
30,000
SHP



RELATIVE RUDDER NORMAL FORCE
SHP = 60,000
B.B.65
TRIPLE SCREW
21,000
24,000
27,000
30,000
B.A.70
TRIPLE SCREW
21,000
24,000
27,000
30,000



TRIPLE 1:2:1
TRIPLE 1:1:1
700
600
500
400
300
200
15,000
30,000
45,000
SHP


97
TRIPLE 3:2:1
TRIPLE 2:1:1
15000
30,000
45,000

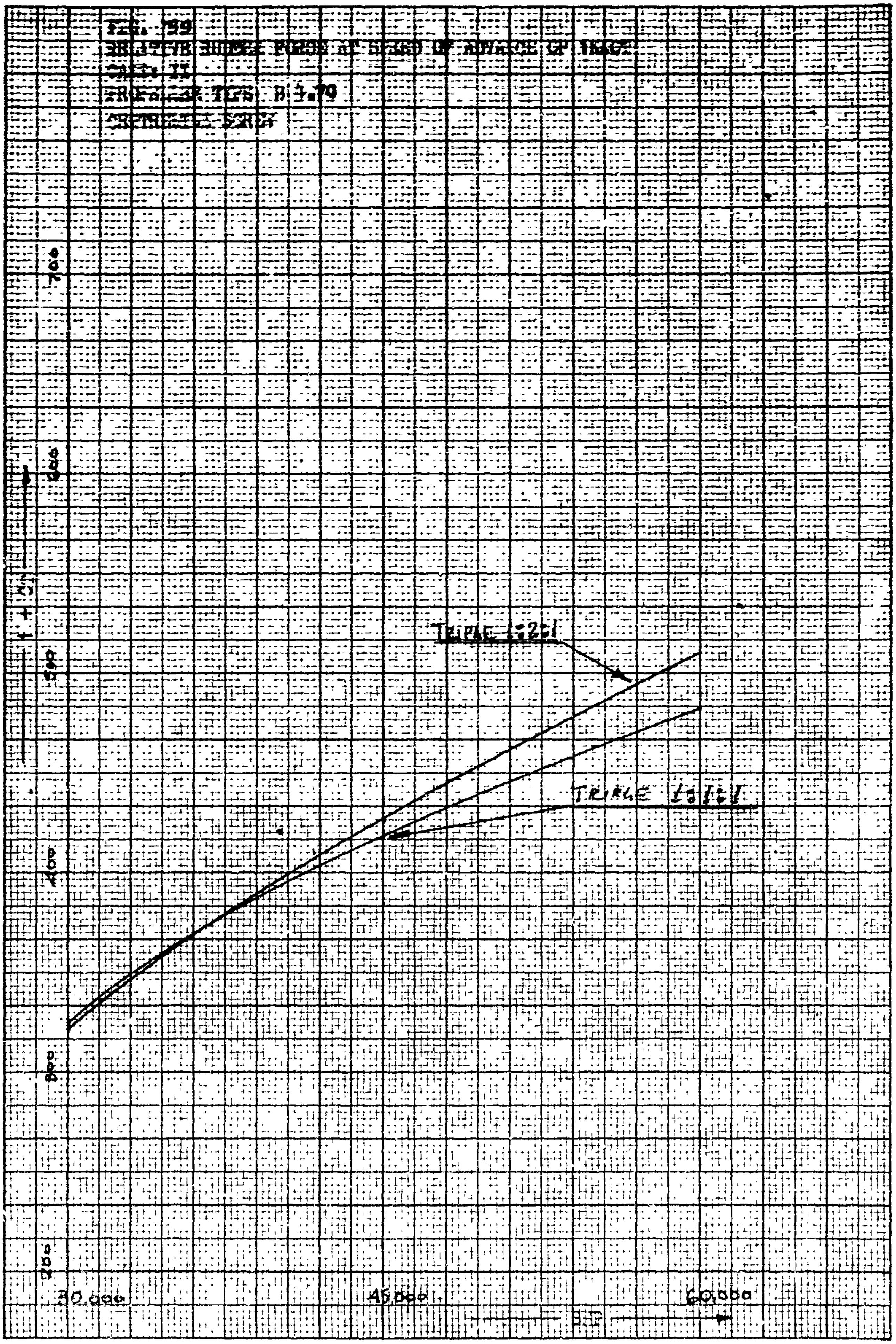


FIG. 739
CASE II
700
600
500
TRIPLE 1:2:1
TRIPLE 1:1:1
400
300
200
30,000
45,000
60,000

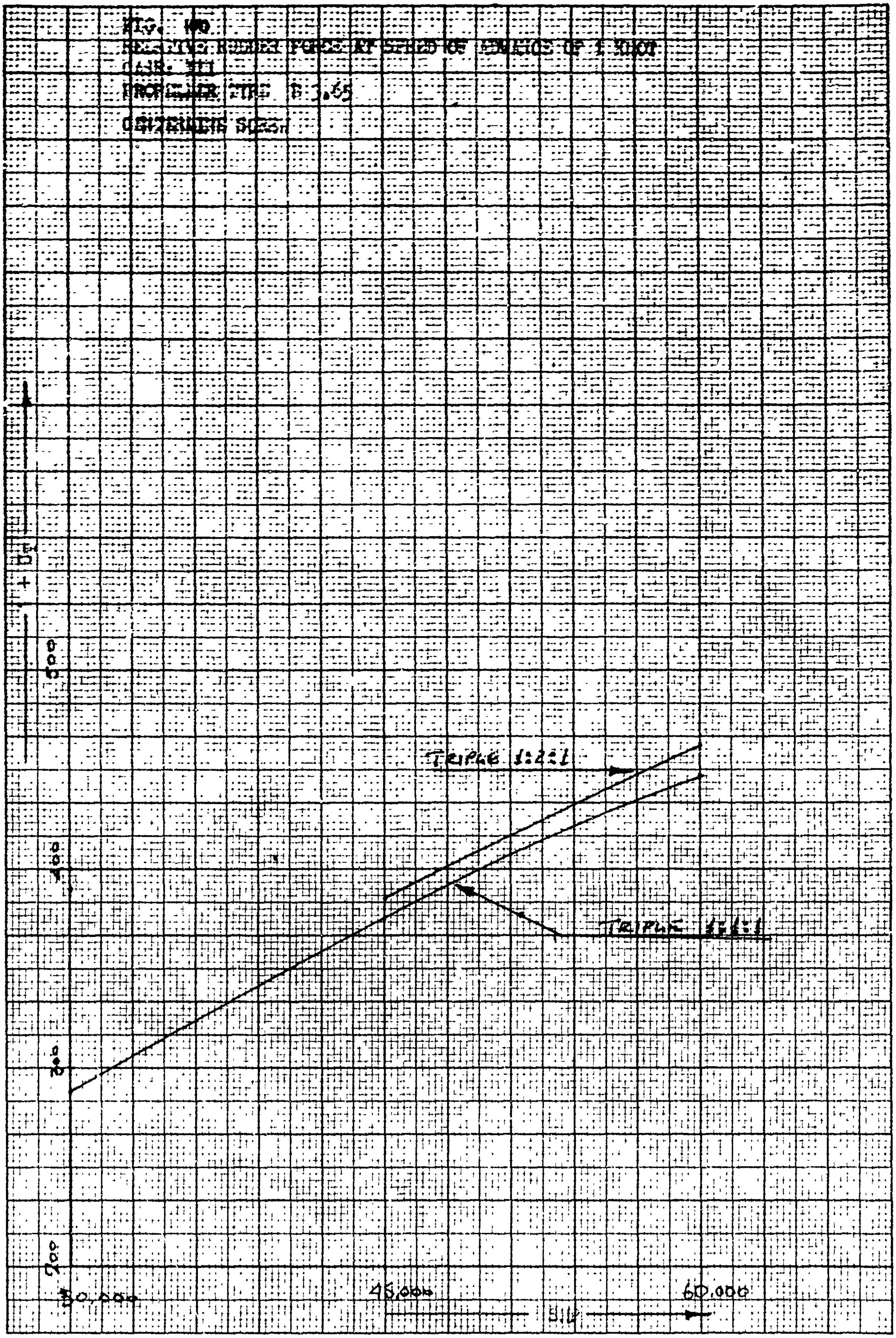

TRIPLE 1:2:1
30,000
45,000
60,000

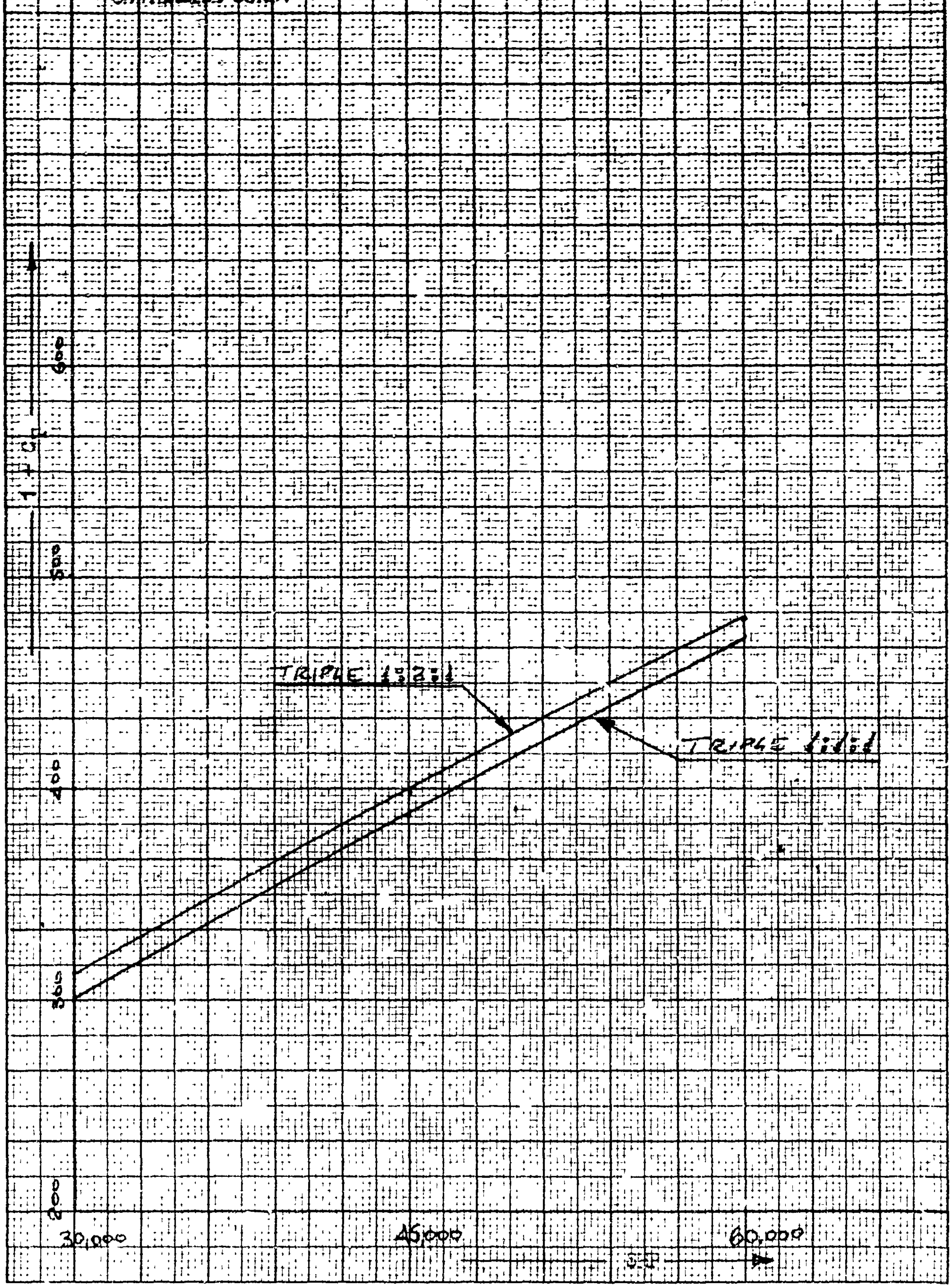
FIG. 96

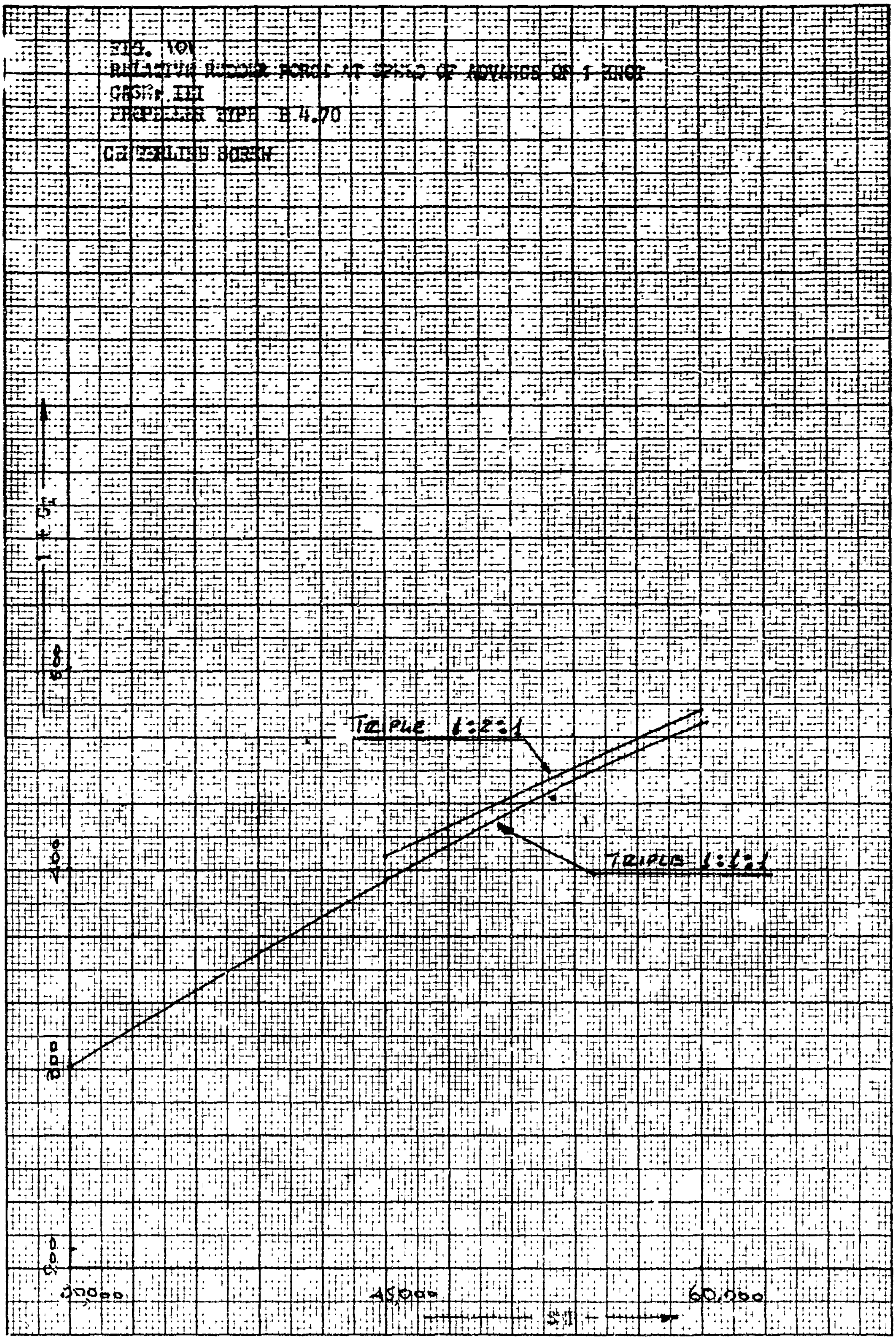
[illegible] RUDDER FORCES AT SPEED OF ADVANCE OF 1 KNOT

[illegible]

PROPELLER TYPE B 3.65

[illegible] SCREW





PROPELLER TYPE B 4.70
TRIPLE 1:2:1
TRIPLE 1:1:1
20000
40000
60,000

FIG. 103

STRESS AT BOLLARD CONDITION

CASE II

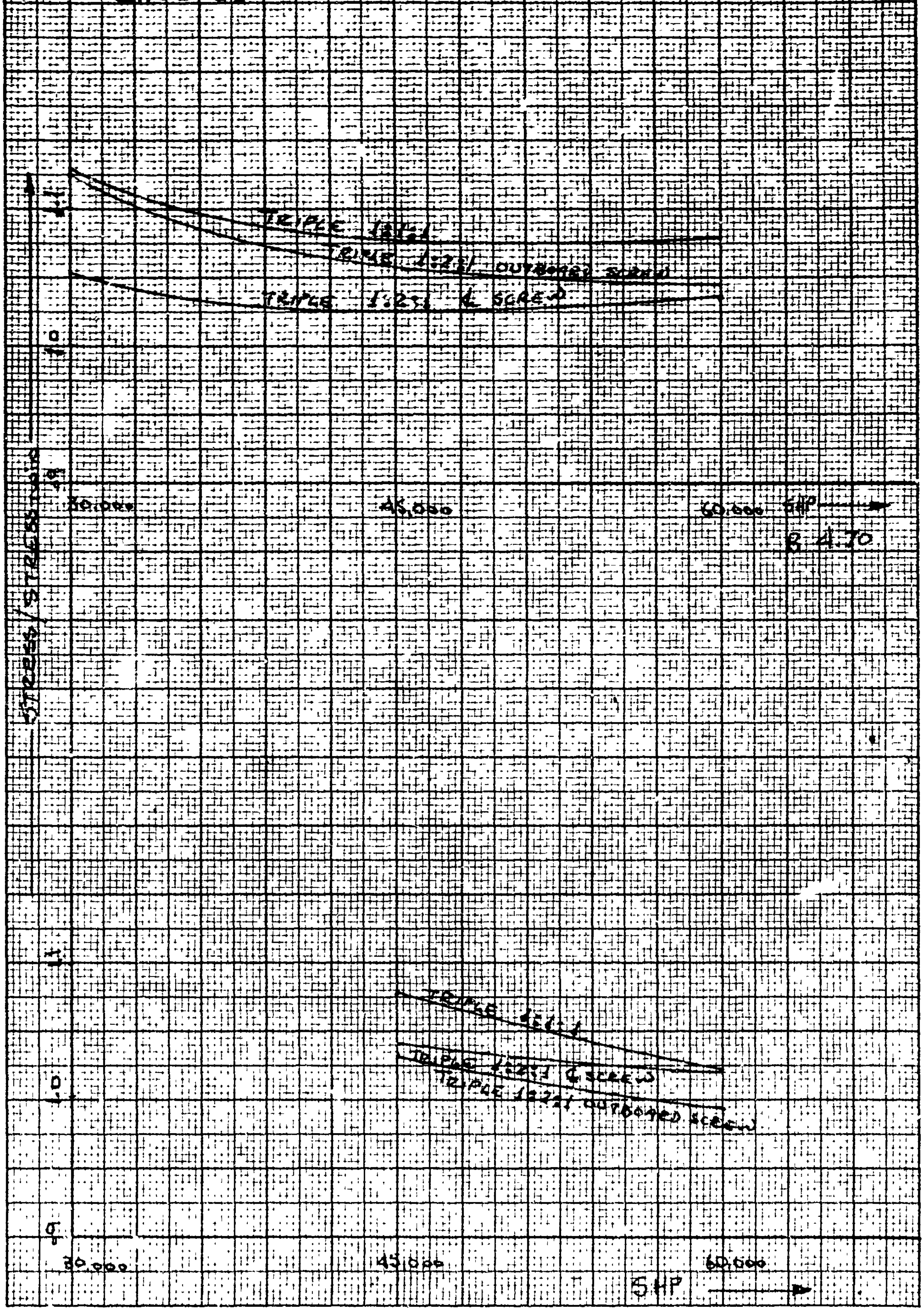
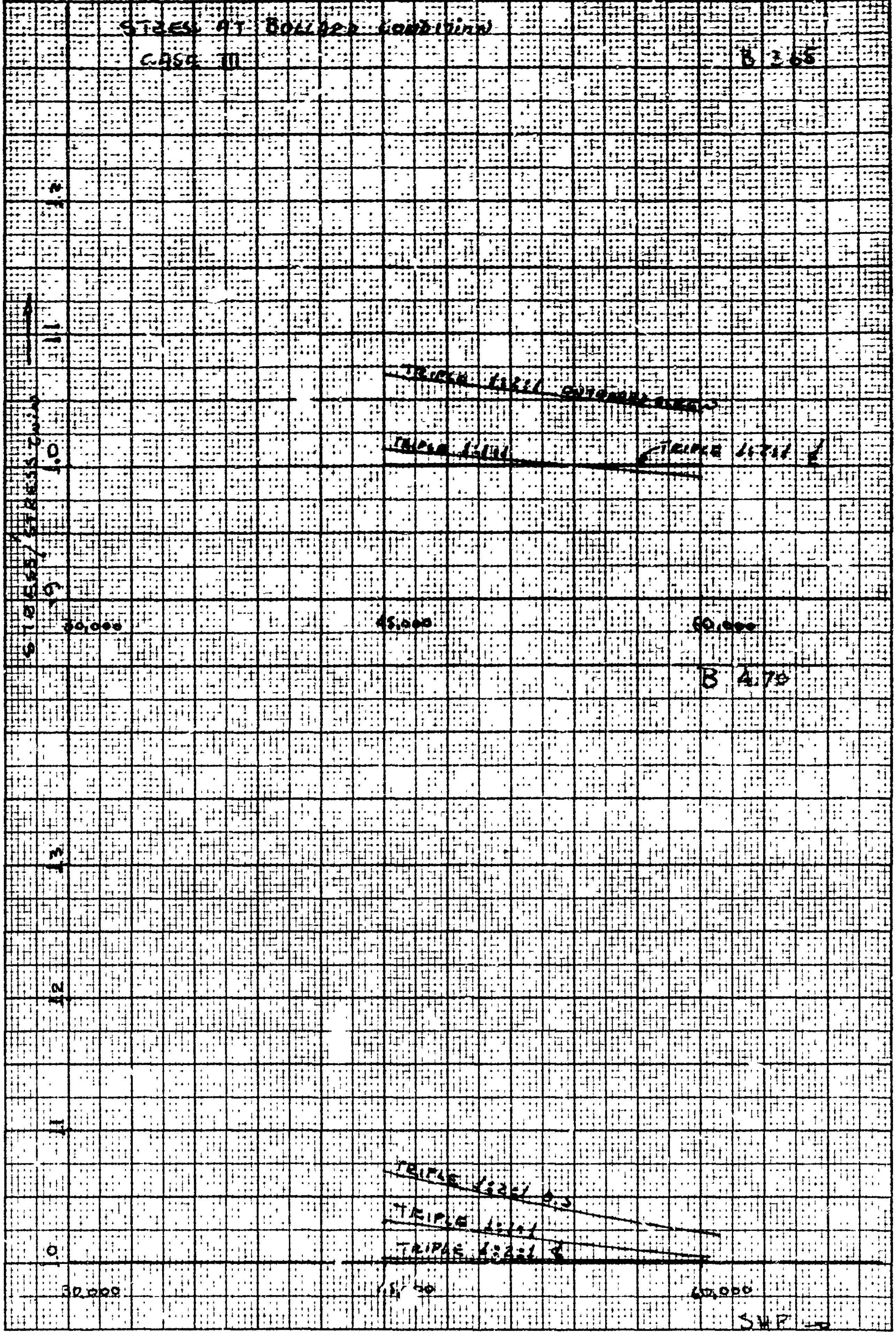
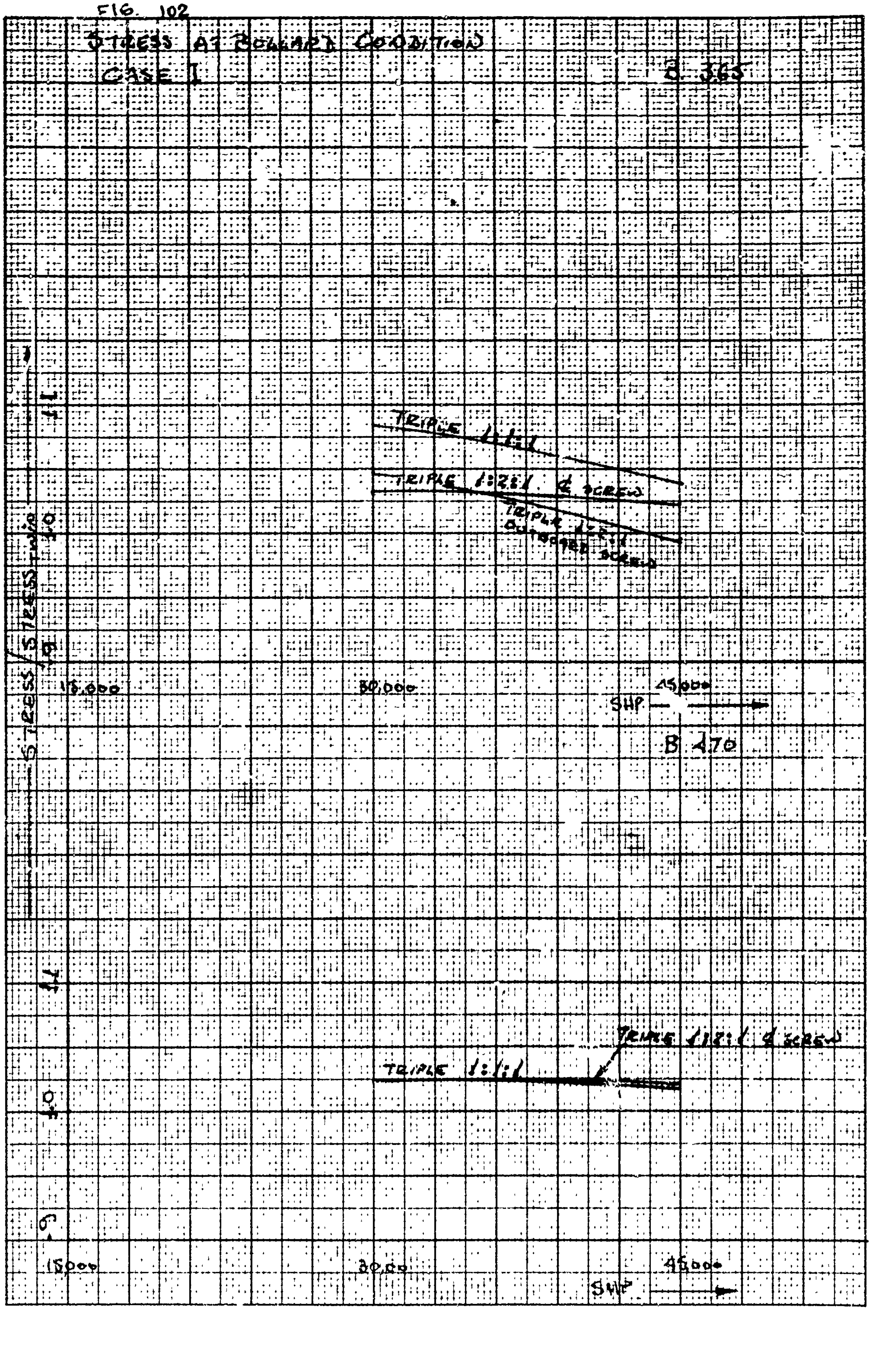


FIG. 104



STRESS AT BOLLARD CONDITION
CASE III
B 3.65
STRESS/STRESS
30,000
45,000
60,000
B 4.70
TRIPLE 1:1:1
30,000
60,000
SWF

FIG. 102


STRESS AT BOLLARD CONDITION
CASE I
B. 365
TRIPLE 1:1:1
TRIPLE 1:2:1 ℄ SCREW
TRIPLE 1:2:1 OUTBOARD SCREW
STRESS/STRESS TRIPLE
1.1
1.0
.9
15,000
30,000
45,000
SHP
B. 470
1.1
TRIPLE 1:2:1 ℄ SCREW
TRIPLE 1:1:1
1.0
.9
15000
30,000
45000
SHP

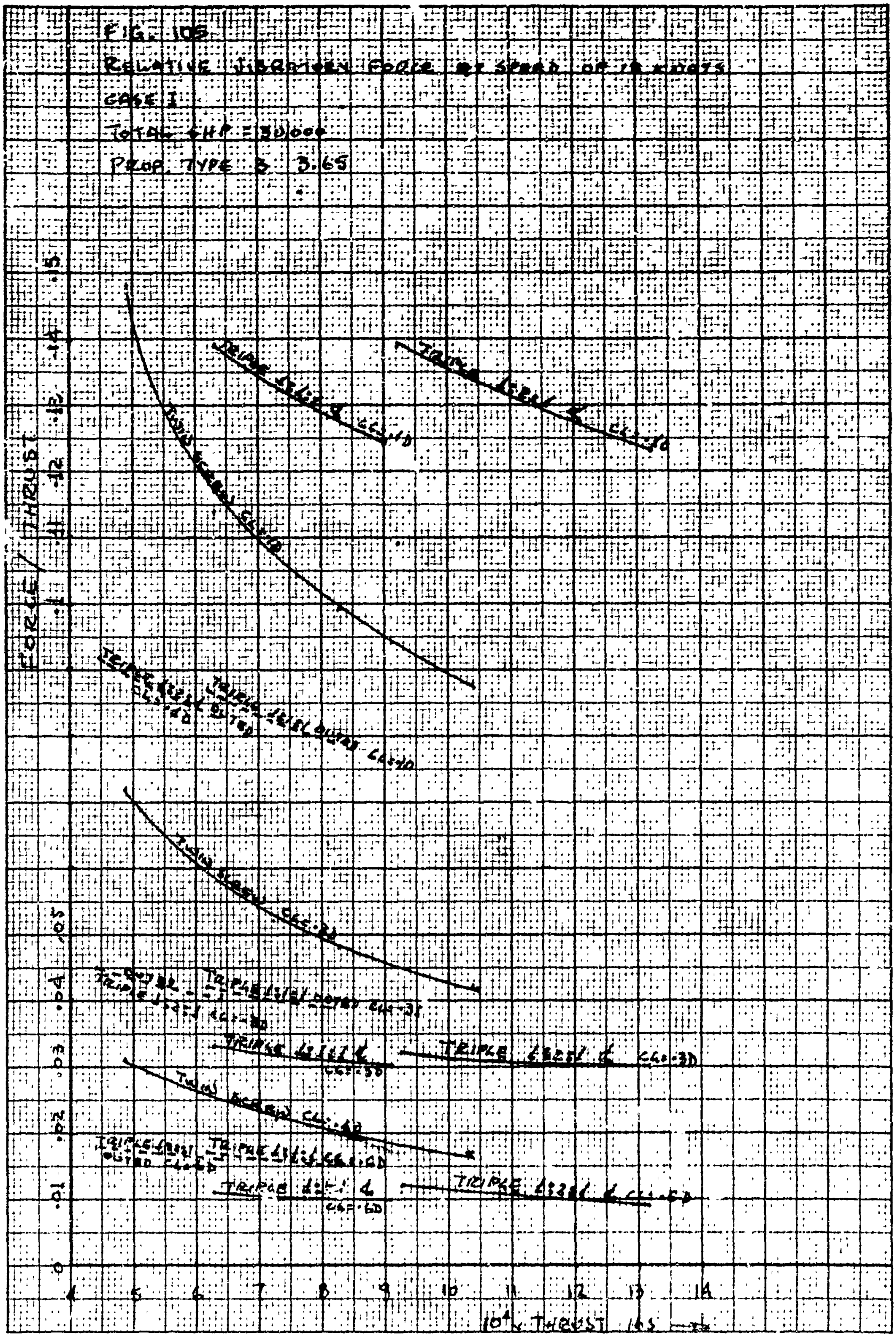


FIG. 105
CASE I
PROP. TYPE 3 3.65
FORCE / THRUST
10⁴ × THRUST LBS
TRIPLE SCREW ℄
TWIN SCREW
TRIPLE SCREW OUTBD
TRIPLE
.01
.02
.03
.04
.05
.11
.12
.13
.14
.15
4
5
6
7
8
9
10
11
12
13
14

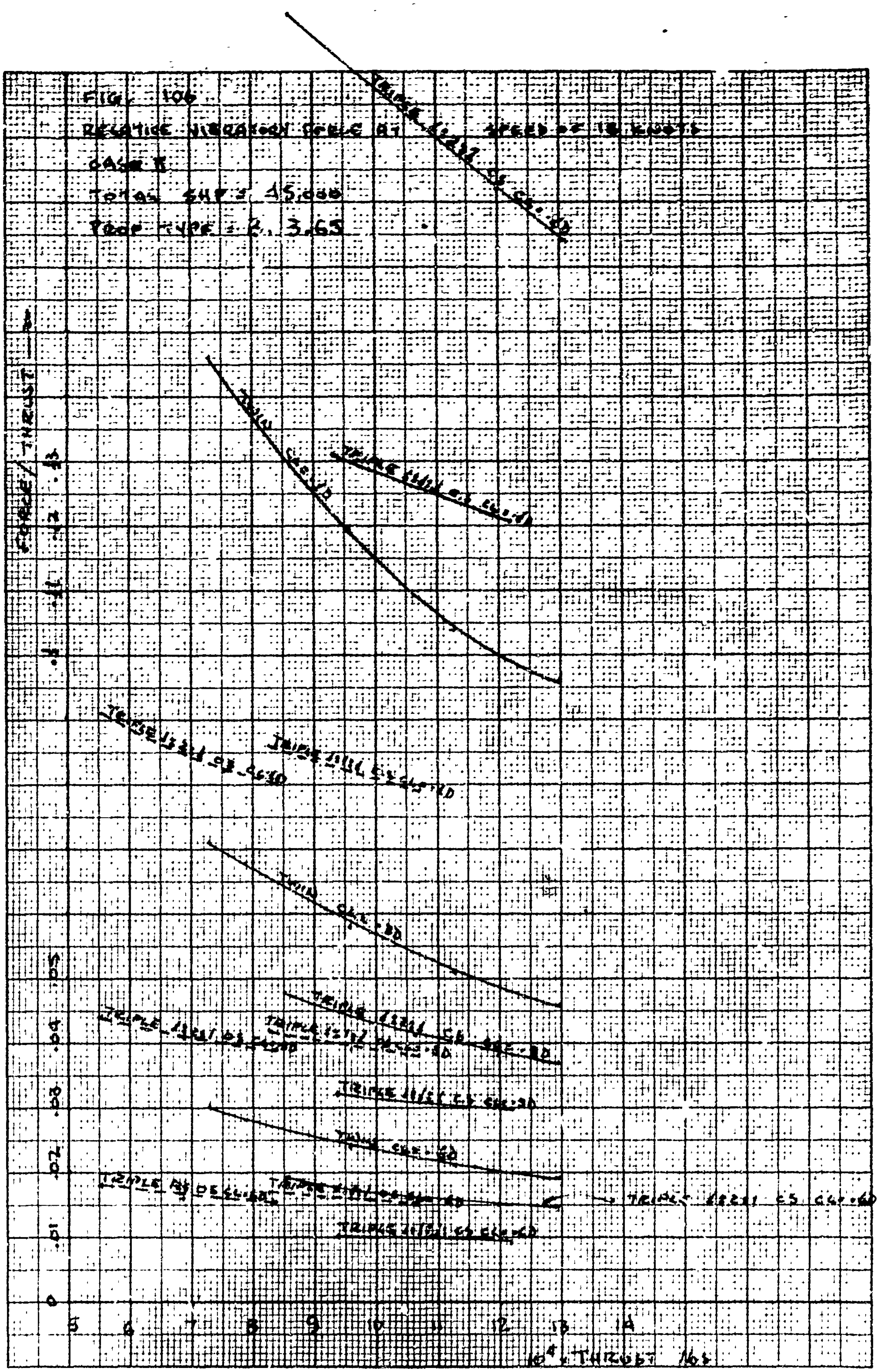


FIG. 106
FORCE / THRUST
.01
.02
.03
.04
.05
.1
.11
.12
.13
0
5
6
7
8
9
10
11
12
13
14
THRUST

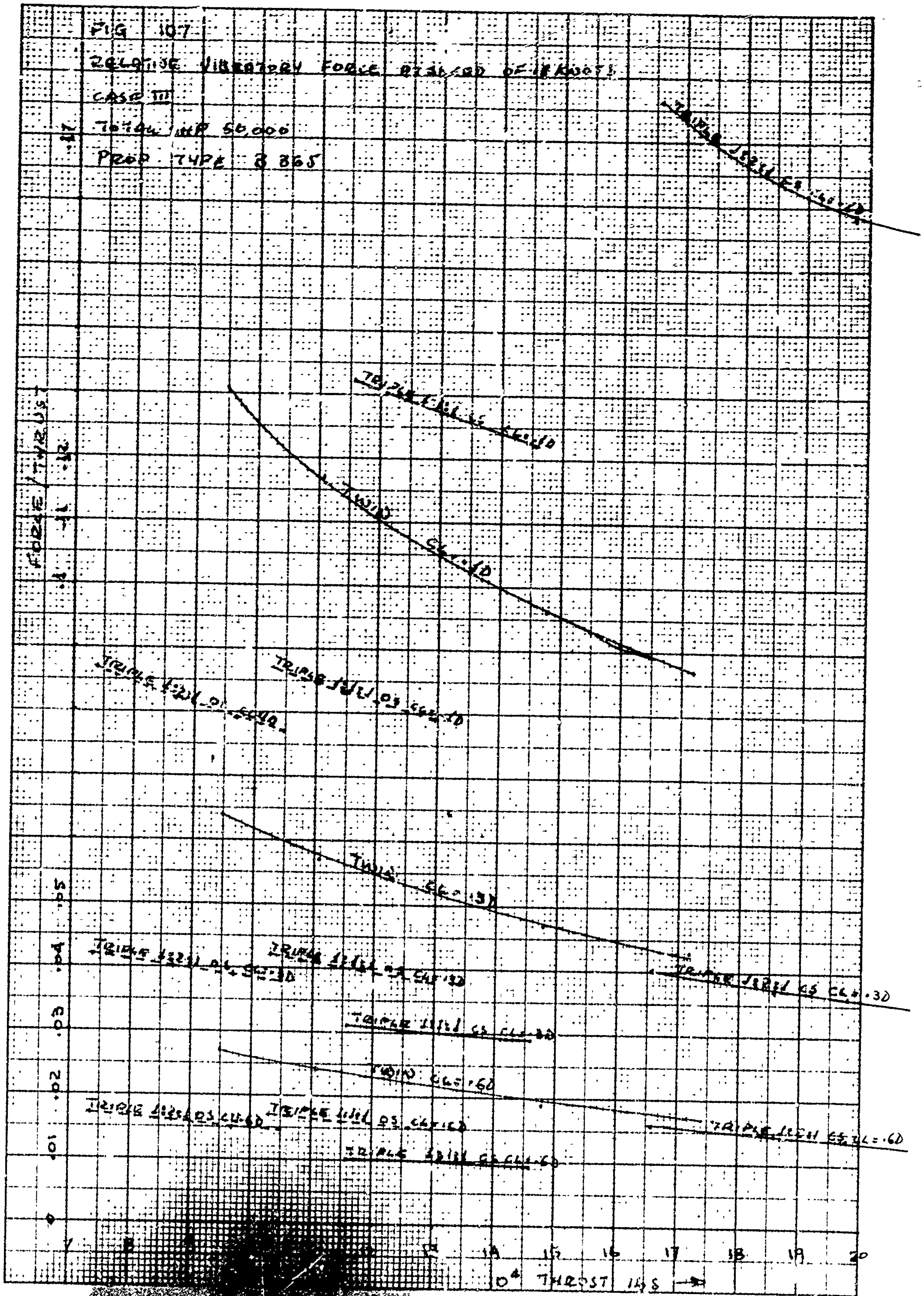


FIG 10.7
CASE III
TOTAL HP 50,000
FORCE / THRUST
TWIN CL=.40
TWIN CL=.30
TWIN CL=.60
.01
.02
.03
.04
.05
7
8
14
15
16
17
18
19
20
THRUST LBS

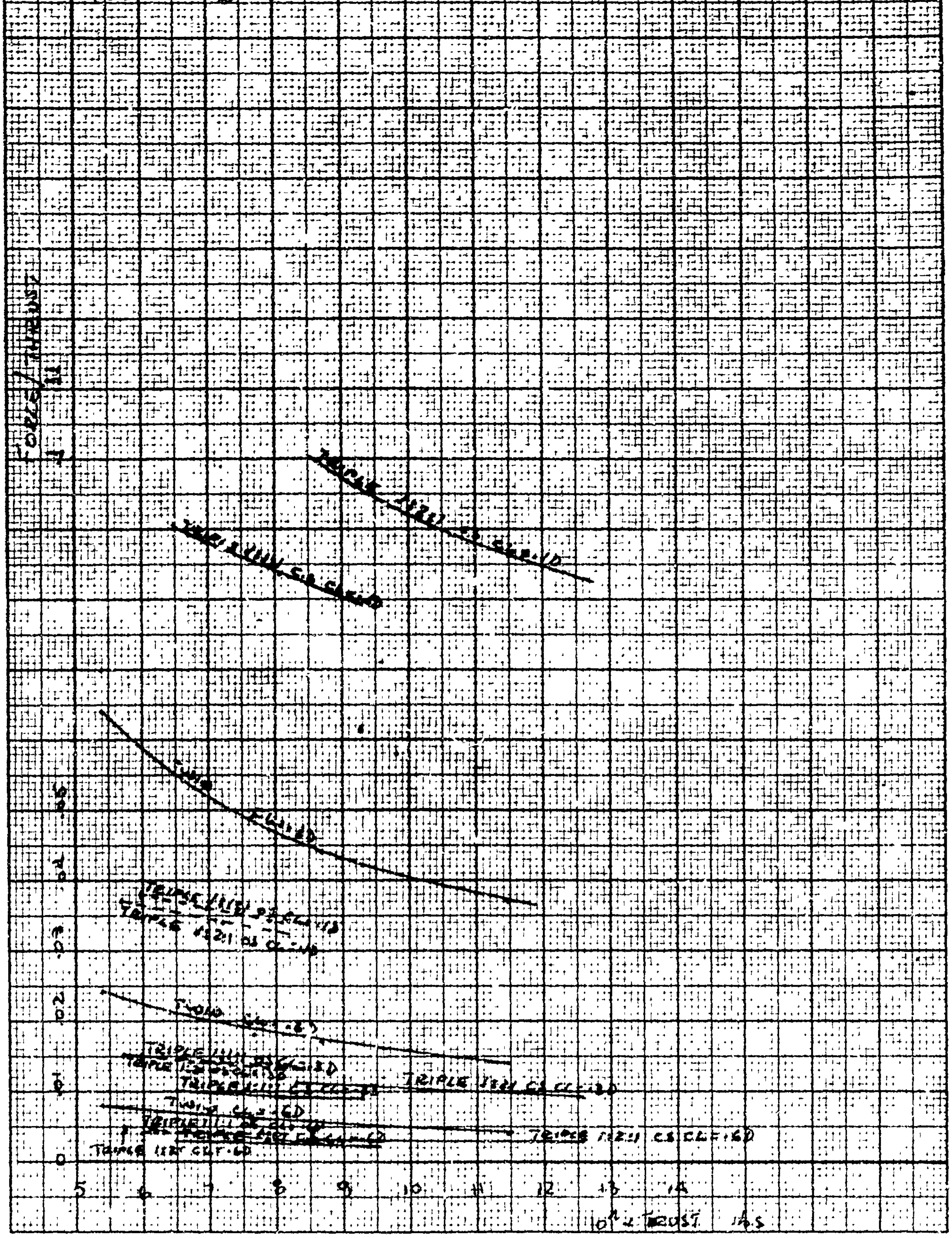
FIG. 108

RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS

CASE 2

TOTAL SHP = 30,000

PROP TYPE B 4.70



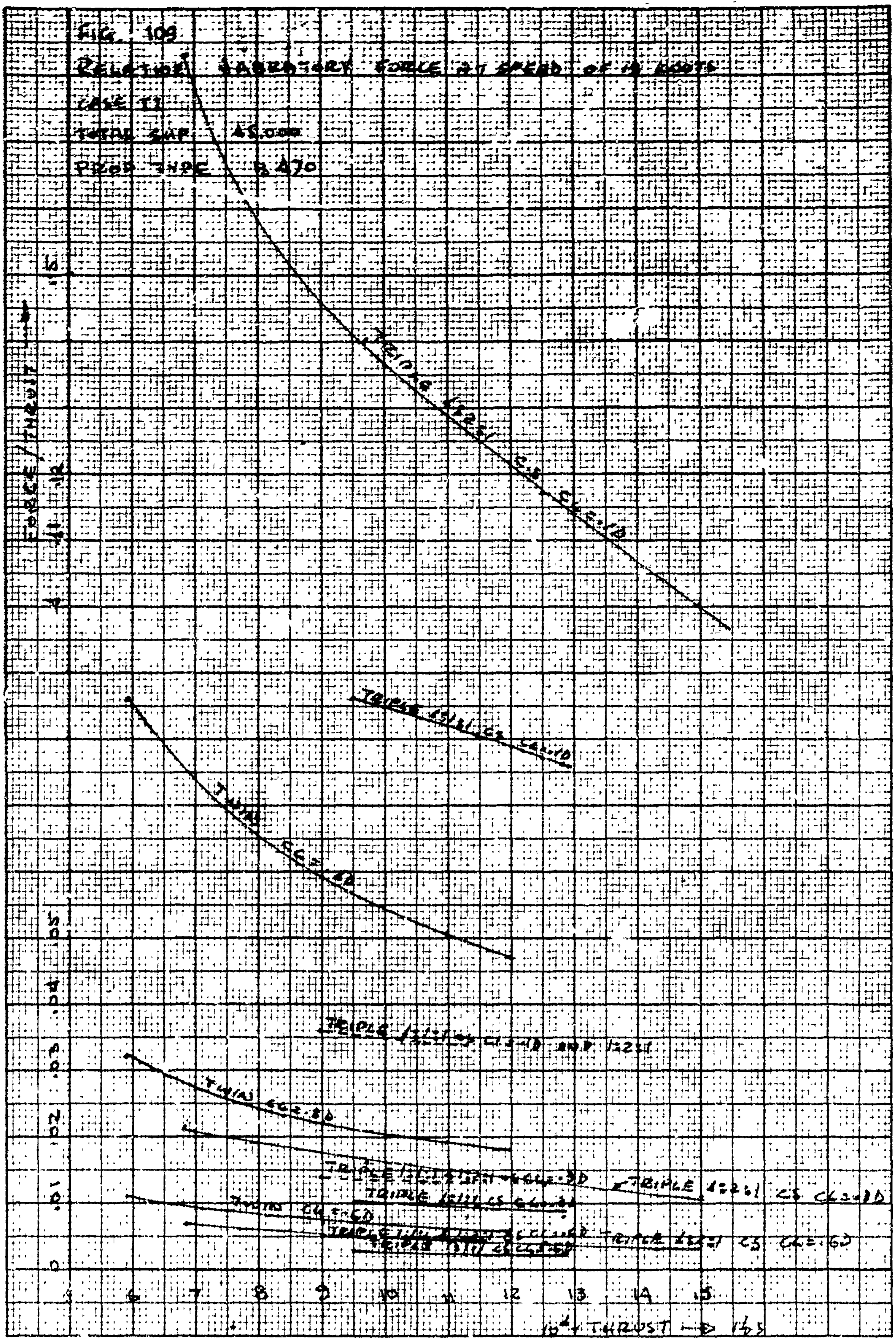


FIG. 109
CASE II
PROP TYPE B 470
TWIN
TRIPLE
.05
.04
.03
.02
.01
0
6
7
8
9
10
11
12
13
14
15
THRUST

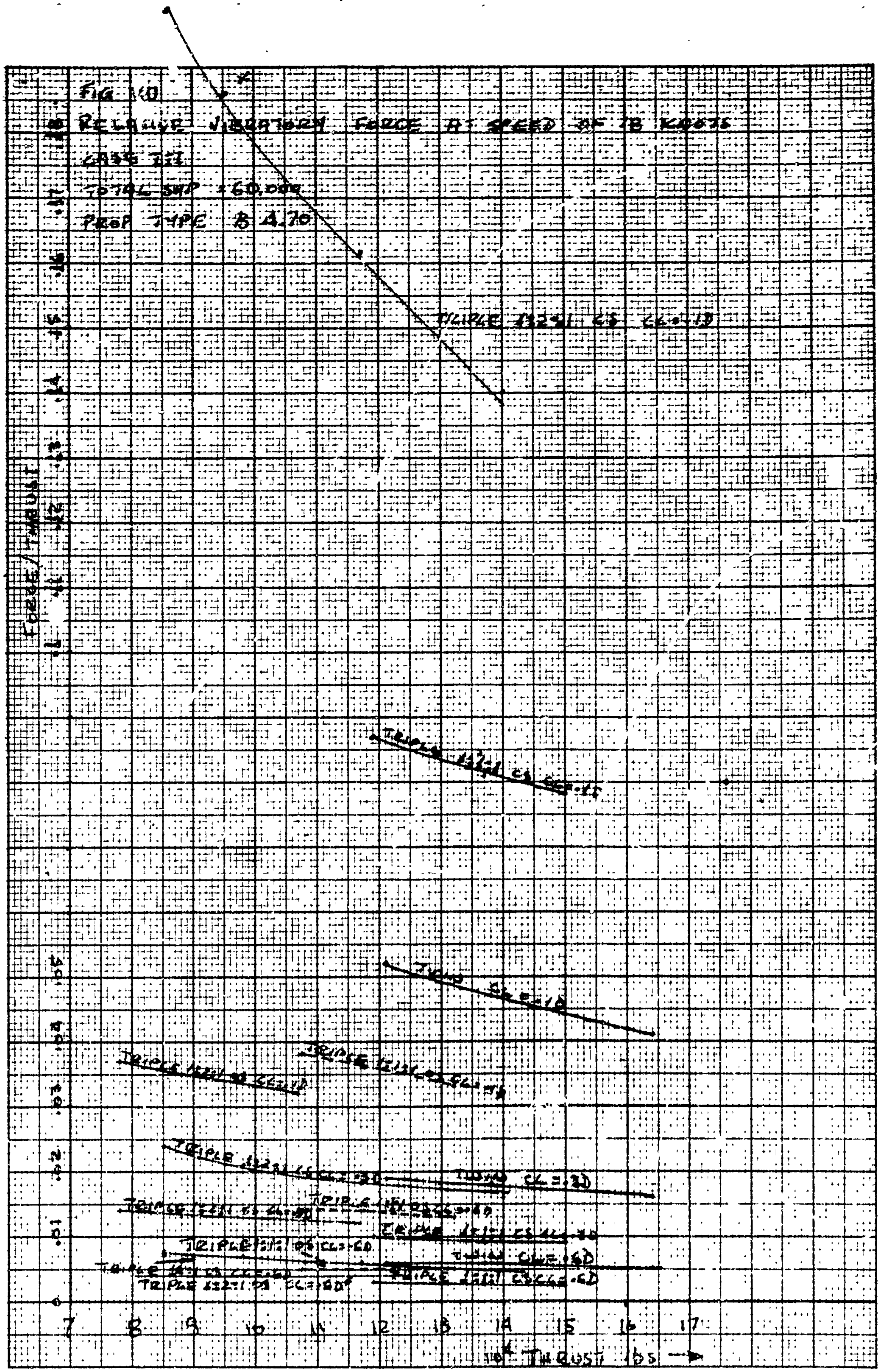
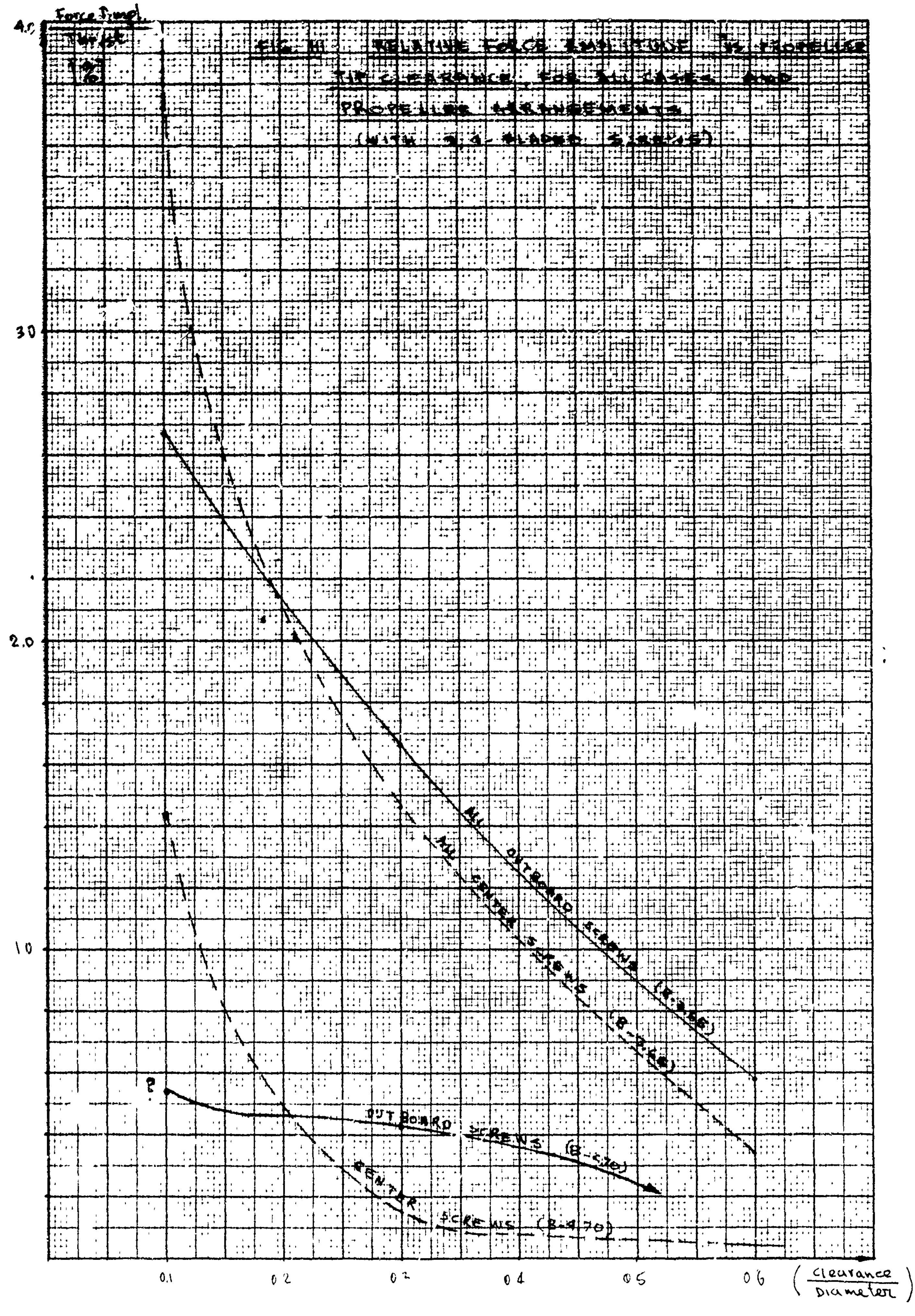


FIG 10
RELATIVE VIBRATORY FORCE AT SPEED OF 18 KNOTS
CASE III
TOTAL SHP = 60,000
PROP TYPE B 4.70
FORCE / THRUST
TRIPLE
TWIN
$\times 10^4$ THRUST lbs


Force Impl.
4.0
3.0
2.0
1.0
0.1
0.2
0.4
0.5
0.6
Clearance / Diameter
ALL OUTBOARD SCREWS
ALL CENTER SCREWS
OUTBOARD SCREWS (B-470)
CENTER SCREWS (B-470)

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13. ABSTRACT

A parametric study of twin and triple-screw propulsion systems for large icebreakers is conducted with respect to technical properties and feasibility limits. The study is devoted to the following aspects in particular: Bollard thrust, ahead, conventional propeller; Bollard thrust, astern, conventional propeller; Bollard thrust ahead and astern, special compromise propeller, designed for astern operation; Propulsive efficiency at advance speed of 1 knot; Propulsive efficiency, free running at 18 knots; Radial and axial clearances between propellers and hull; Steering and maneuverability; Propeller excited hull and shaft vibrations; Propeller strength; Cavitation--further, the effect of the following parameters had to be considered: Blade number, three versus four blades; Hub size, solid and detachable blade screws; Propeller diameter; Area and power splitting ration, 1:1:1 versus 1:2:; Powering (SHP).

KEY WORDS

ICEBREAKER
PROPELLCRS
SCREWS
TWIN
TRIPPLE
STUDY
FEASIBILITY
BOLLARD THRUST
PROPULSIVE EFFICIENCY

UNCLASSIFIED
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14. KEY WORDS	LINK A		LINK B		LINK C	
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ICEBREAKERS						
PROPELLERS						
SCREWS						
TWIN						
TRIPLE						
STUDY						
FEASIBILITY						
BOLLARD THRUST						
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